Harper Adams University

Proceedings of the 5th Symposium on Agri-Tech Economics for Sustainable Futures

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Global Institute for Agri-Tech Economics,

Food, Land and Agribusiness Management Department,

Harper Adams University

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Proceedings of the 5th Symposium on Agri-Tech Economics for Sustainable Futures

Global Institute for Agri-Tech Economics (GIATE)
Food, Land & Agribusiness Management Department
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Anders Wijkman

Honorary President of the Club of Rome, Chairman Climate-KIC, Sweden

Presenter Profile

Anders Wijkman is an opinionmaker and author. Anders is a former member of the European Parliament, honorary president of the Club of Rome, member of the IRP (International Resource Panel) - a UN expert- body “to build and share the knowledge needed to improve the use of our resources worldwide”. He is, as well, Chair of Circular Sweden, a platform for producers, retailers and recycling companies to advance the Circular Economy. He is a member of the Royal Swedish Academy of Sciences, the World Academy of Art and Science and the World Future Council.

Keynote Presentation: Economics of agri-tech policy, regulation and standards

Professor James Lowenberg-DeBoer

Land, Food & Agribusiness Management Department, Harper Adams University, Shropshire, Newport, TF10 8NB, UK.

Presenter Profile

Prof. James Lowenberg-DeBoer holds the Elizabeth Creak Chair in Agri-Tech Applied Economics at Harper Adams University (HAU), Newport, Shropshire, UK. He is responsible for economics in the Hands Free Farm (HFF) team at HAU. He is also co-editor of the journal Precision Agriculture and past president of the International Society of Precision Agriculture (ISPA). His research focuses on the economics of agricultural technology, especially precision agriculture and crop robotics. Lowenberg-DeBoer's research and outreach is founded in hands-on experience in agriculture, including production of maize and soybeans in NW Iowa in the USA.

Keynote Presentation: Exploring agriculture-based mitigation in the pursuit of circular economy. Food tree crops ecosystems as a net sink of CO_2

Professor Konstantinos Bithas

Panteion University, Greece

Presenter Profile

Kostas Bithas is a Professor in Environmental and Natural Resources Economics at the Panteion University, Department of Economic and Regional Development, Athens, Greece and Member of the Board of Directors of the Institute of Urban Environment and Human Resources Research team on Environmental Economics and Sustainable Development (www.eesd.gr). Academic fields: Sustainable Development, Ecological Economics, Natural Resources Economics, Environmental - Economic modeling, Environmental impact assessment, Transport Economics, Decision making, Policy evaluation.

The Impact of Female Tertiary Education and Climate Change on Economic Growth in Developing Countries

Aya Moataz and Christian Richter

Coventry University in Egypt at The Knowledge Hub Universities, Cairo, Egypt

Abstract

This study examines how female tertiary education and climate change affect economic growth in a set of 33 chosen developing countries from around the world. Previous literature examines the relationship between gender inequality and economic growth and climate change and economic growth both theoretically and empirically, in this study empirical analysis of panel data set will be made using a cross section fixed effects model.

Annual growth rate of female tertiary graduates with a ten-year lag, gross fixed capital formation, and gross domestic product growth rate with a one-year lag have been found to have a positive and significant effect on the economic growth rate for developing countries. A significant and positive relationship has been found between the annual growth rate of mean temperature and annual growth rate of gross domestic product where the annual growth rate of gross domestic product is the independent variable.

Enrolment rates or years of schooling of primary and secondary levels have been used in previous literature as proxies for female education; in this study the annual growth rate of female tertiary graduates is used to highlight the importance of tertiary level education and graduate growth rate is used to provide better proxy for the completion of the whole period of study and not only enrolment. Additionally, climate change is usually included in economic models as a dependent variable, in this study an attempt to explore climate change as an independent variable is made to provide more insights into the nature of the relationship between climate change and economic growth.

Keywords

Developing countries; economic growth; female tertiary education; gender inequality; climate change; panel data.

Presenter Profiles

Aya Moataz graduated from the German University in Cairo with double majors in Finance and Economics. She then started her academic career as a teaching assistant and then an Assistant Lecturer of Economics at the German University in Cairo. She received her master’s degree in Economic Development with highest honors from the GUC and managed to study two more majors, namely, Strategic Management and Marketing. Currently, Aya is an Assistant Lecturer of Finance and Economics at the Business School at Coventry University branch in Egypt at The Knowledge Hub Universities.

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Introduction

This study aims to examine the impact of female tertiary education and climate change on economic growth in a set of 33 developing countries from the years 2001-2019. In previous literature the focus has been mainly on female primary and secondary schooling effects, limited studies have examined the effect of female tertiary education on economic growth. This study focuses on the tertiary educational level in attempt to further explore a less visited aspect of female education and its effect on economic growth. Also, previous literature mainly focuses on climate change as a dependent variable and not an independent one, which encouraged the inclusion of this specific variable in the study to test for a different direction for the relationship between climate change and economic growth.

This paper is structured as follows: Firstly, previous literature on gender inequality, education, climate change and economic growth along with the theoretical approach on which the study is based is provided. Secondly, the methodological approach used is discussed. Thirdly, results of the analysis are explained. Followed by a discussion section where results are compared with those of previous scholars. Finally, a conclusion with the main finding is provided along with limitations, policy, and future recommendations of the study.

Gender Inequality in Developing Countries

Although women and girls have made significant efforts towards achieving gender equality since 1990, they are yet to achieve their goal. Gender inequality is the discrimination against women which leads to hindering female's development; it includes yet is not exclusive to discrimination in health, education, political affairs, job opportunities, etc. A main source of this gender inequality is the hindrances that women and girls face in societies (UNDP HDR, 2015).

The commonly used method for determining the relationship between gender inequality and economic growth has been through examining effect of gender gaps on economic growth through the regression of growth variables, some of which are proxies for gender inequality on a country's growth rate represented by per capita income (Cuberes and Teignier,2014). A positive relation between women's status and developing socially and economically has been emphasized by social workers over time. The educational gender gap was highlighted by comparing between the richest and poorest quartiles in 1990, where in the richest quartile 51% of adult women had obtained secondary level education, while the percentage was an 88% for men. On the other hand, the poorest quartile only 5% of adult women had any secondary education which is half of the level for men (Dollar and Gatti,1999). Disparities in both productivity and salaries between women and men arise due to the isolation of women in a limited number of fields. Examples of this segregation include Nigeria and India, where in Nigeria in the year 2007 the ratio of women to men's earnings was 60c:1 dollar and in India it was 64c:1 dollar (World Development Report,2012).

On the other hand, previous literature indicates there can be a positive effect of the gender gap given that the pay gap remains constant, and the educational gender gap is reduced, this provides qualified female labour that accept low wages. Although there have been arguments against this finding since on the long-term wages cannot remain low and eventually will be subject to pressure that will elevate female wages (Seguino,2000 a, b).

Theoretical background

One of the most prominent growth models in literature is the Solow Neoclassical Growth Model (1956). The model indicates that given the fact that two economies share equal rates of savings, depreciation, growth of labour force and growth in productivity will lead to the conditional convergence to same income level (Solow, 1956).

$$Y = K^{\alpha}. (AL)^{1-\alpha} \quad (1)$$

In the model equation (1), gross domestic product is represented by Y, Capital Stock (both human and physical capital) represented by K, labour represented by L and A as an indicator of labour productivity given that its growth rate is external (at approximately 2% for developed countries but variant for developing countries depending on whether they are in a period of stagnation or improvement). The assumptions of the Solow Growth Model are:

1. Compensation for factors of production whether capital or labour depends on marginal physical productivities.
2. Flexibility of both prices and wages in economy.
3. Full employment of both labour and capital available.
4. Possibility of substituting labour for capital and vice versa.
5. Neutrality of Technological progress
6. A constant saving ratio.

Assumptions 1-3 imply a perfectly competitive market. Model has been found to be more relevant in developed economies rather than developing ones (Todaro, 2009).

According to Figure 1 for Unemployment percentage for the developing countries that have been used in this research, none of the countries fulfil the assumption of full employment level in the economy proposed by Solow (1956), therefore violation of one or more of the assumptions of the model affects the eligibility of the model thus requires its modification.

The proposed modifications upon which our model is built is to use the annual rate of growth of female tertiary graduates instead of Labour and using annual growth rate of gross fixed capital formation as a representative of physical capital in the model. Additionally, climate change is represented in the model through annual growth rate of mean temperature, as in more recent decades the impact of climate change has become more prominent than earlier years (1956) when the Solow model was first developed.

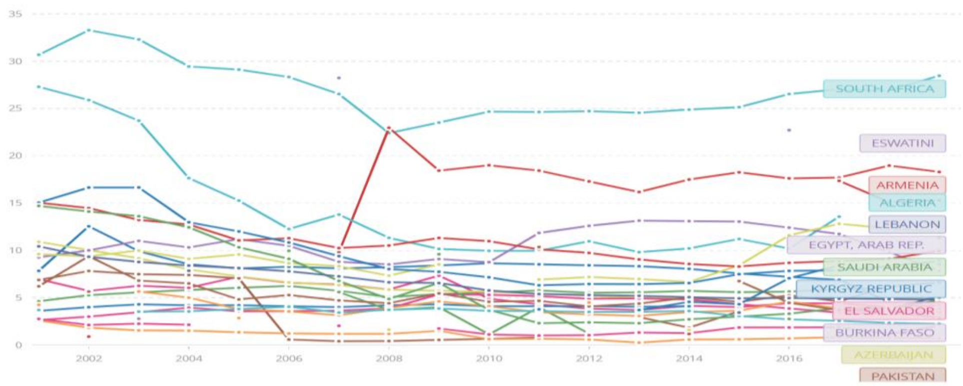

Figure 1: Unemployment, total (% of total labour force) (2001 – 2019). Source: World Bank data (2021) (https://bit.ly/3rC2szH)

Education, Economic Growth and Sustainable Development Studies

The achievement of sustainable development and a wholesome, productive life for all depends on the provision of quality education and lasting learning opportunities (Guterres,2017). “Whether we view sustainable development as our greatest challenge (Annan, in UNESCO 2005) or a subversive litany (Lomborg 2001), every phase of our education system is being urged to declare its support for education for sustainable development (ESD)” (Vare & Scott,2007).

Differences in educational standards and public expenditure on education shape the two most common reasons behind the existing per capita income gap between developed and less developed countries. Improvement in developed countries has not been exclusive to literacy rates in general, but more specifically the reduction of the disparity between the female to male rates (Akram et al.,2011). Despite the advancements made in gender equality, empowerment of women and enrolment in different educational levels, the higher educational levels suffer from the widest gender disparities in several regions and countries (Guterres,2017).

The importance of examining the relationship between education and economic growth can be attributed to two main reasons. Firstly, from a generic perspective to either be a beneficiary of or contributor to the progression of science, education is a must. Secondly, and more precisely, a vast pool of econometric research has made a link between one’s attainable income level and the educational level reached. If there are wage differences that arise in many cases due to differentials in education, then the same could apply for countries as well. If production per labour is dependent on the individual’s education, and expenditure on education does provide a kind of return, in the same manner that expenditure on fixed capital does. Then it is reasonable to view expenditure on human capital as an alternative to that of fixed (Oztunc et al.,2015).

Empirical analysis on gender inequality in education and economic growth mostly covers period from 1960-2000. The literature in this period analyses the effect of female education on economic growth from two perspectives; the first perceives effect of each female and male education independently while the second uses a ratio for female to male education in the analytical process (Licumba et al.,2015).

Firstly, (Barro and Lee,1994) paper was one of the first in the perception of female and male education independently and their effect on economic growth. The (1994) paper by the title of Sources of Economic Growth used a sample of 115 countries and years of schooling as a proxy for female education. It indicated that both secondary school attainment and life expectancy are significant when it comes to growth regressions, emphasizing that when it comes to comparing both, life expectancy has the more significant effect. They also refer to the long run effect on growth which arises from the impact that schooling has on decisions regarding both quantity and quality of children.

Four of the countries in the sample of Barro and Lee’s (1994) study namely (Hong Kong, Singapore, Taiwan and Korea) are characterized by advanced growth levels and low levels of female education which lead to attributing the study results reached to the presence of these four countries and the indication that if the female variable were to be removed the statistical significance of the male educational variable would be in question (Stokey,1994). In a different study, a division according to degree of industrialization in the sample of developing countries was made, resulting in the significance of female secondary education in only the industrialized portion of the sample (Dollar and Gatti,1999).

A classification according to a country's level of human capital was applied in another study to the sample of developing countries and accordingly 11 developing countries were split into economies of high and low human capital. Relevance of female primary education was present only in developing countries characterized by low human capital (Kalaitzidakis et al.,2001).

Brummet (2008) used Barro and Lee's (1994) data set, yet only 72 out of 138 countries were used due to the lack of available data the period studies extended from 1960-1985. As previously mentioned, Barro and Lee's (1994) data set suffered from multicollinearity issues, multicollinearity was accounted for by Brummet (2008) by introducing the natural log of the ratio between men's and women's education, this adjustment decreased the multicollinearity problem greatly yet did not manage to eliminate it completely. Results for the study highlighted the inverse relation between underinvestment in women's education and economic growth. Also highlighted when comparing discrepancies in primary education and secondary education, primary education had the larger impact, and those results were more prominent in developing nations. In their study (Baliamoune - Lutz and McGillivray, 2009) used panel data for 31sub- Saharan African and 10 Arab countries throughout a period from 1974 to 2001 to test for the relation between the ratio of 15–24-year-old literate females to males and growth for countries in sample. The finding indicates the negative relationship between gender inequalities in literacy and growth.

In a study conducted on a sample of countries from the MENA region covering the period from 2000-2014, it was found that despite the significant and fast increase in educational attainment female labour force participation did not match that increase. It was also highlighted that literature commonly attributed this to supply side effects, while the study argued that changes in the nature of employment opportunities for women such as decrease in public sector employment might have led to this decreased participation (Ragui et al., 2018). In another paper that surveyed and analysed the trends of female labour force participation in developing countries, it was found that increased female education, economic growth and decreased fertility do not necessarily reflect positively on the female participation rate, but specific conditions must be provisioned for this to happen. Such conditions are associated with phase of educational growth, household situation, the extent to which educated women are limited to specific jobs, and expansion in employment opportunities preferred by educated women (Klasen,2019).

One of many variables that affect GDP is climate change. The link between female education, GDP growth and climate change can be highlighted in Blankespoor's et al. (2010) study where developing countries were studied throughout the period 1960 – 2003, the study concluded that countries which had higher percentages of educated females were more capable of enduring the climate change related disasters in comparison to other countries that were less fortunate even though they enjoyed similar income and climate.

Impact of Climate change on Economic Growth

The degree of economic activity determines the extent of humans' generation of greenhouse gases (GHG). Therefore, models of economic growth have been extensively used in literature on climate change. Nevertheless, the likelihood of climate change impacting economic growth is also present. There are varying and intricate methods to which those impacts affect economies through trends in production and consumption, available resources, and productivity (Eboli et al.,2010). Intra-generational equity is another characteristic of climate change, where more wealthy economies have more moderate climates in comparison to much poorer ones such as sub-Saharan Africa, which also happens to have less financial and institutional capabilities to mitigate effects of climate change (Tsigaris and Wood,2016).

In a study that uses a multi-regional Computable General Equilibrium (CGE) Model, it was found that climate change impacts were experienced by developing countries the most, where it acts as a hurdle in the path of income convergence and equity. Developing countries such as China and India suffered from a significant negative impact on real GDP (Eboli et al.,2010). In another study where, overall economic damaged cause by climate change was assessed, it was projected that losses in the range of 2-20% of GDP are expected to occur in the poorest third of countries by the end of the 21st century (Solomon et al.,2017). In a different study, a cross validation exercise was performed on 800 models depicting the temperature-GDP relationship. Results showed that the impact of marginal temperature on GDP growth globally was not statistically significant (Newell et al.,2021).

In previous literature the focus has been mainly on female primary and secondary schooling effects on economic growth, yet limited studies have examined the effect of female tertiary level education on economic growth. This study focuses on the tertiary educational level in attempt to further explore a less visited aspect of female education. Additionally, from a climate change perspective, this study attempts to incorporate mean temperature in a modified Solow growth model to account for how climate changes can impact GDP growth where in previous literature this relation is mainly study in separate models as mentioned earlier such as CGE models. Accordingly, the proposed hypotheses for this study are:

H1: Female tertiary education does affects economic growth.

H2: Mean temperature affects economic growth.

Methods

Study area and data collection

A balanced panel of data is used consisting of 297 observations from 33 developing countries from all over the world covering the period from 2001-2019, namely: Kazakhstan, Kyrgyz Republic, Azerbaijan, Armenia, India, Pakistan, Vietnam, Thailand, Philippines China, Bahrain, Lebanon, Saudi Arabia, El Salvador, Mexico, Panama, Brazil, Colombia, Paraguay, Ecuador, Uruguay, Algeria, Egypt, Nigeria, Democratic Republic of Congo, South Africa, Kenya, Mozambique, Burkina Faso, Senegal, Rwanda, Burundi and Eswatini. The choice of these specific countries and timeframe is based on the Millennium Development Goals 2015 report and its Regional Fact Sheet, as specific regions were applauded for their progress in the millennium development goals and more specifically education. Accordingly, this study's developing countries were targeted from the aforementioned regions. The period from 2001-2019 was chosen to coincide with the timeframe set for achievement of the goals from 2000-2015 so that impact of the goals is highlighted whether for education or environmental stability.

The cross-sectional fixed effects model is used for the panel data analysis with a period random effects specification. The dependent variable is the annual growth rate of real gross domestic product per capita (GR_R_GDP) obtained from the World Bank Data. Independent variables are annual growth rate of gross fixed capital formation (GR_FC) obtained from World

Bank Data, annual growth rate of female tertiary graduates (GR_F_TG) data was triangulated and interpolated from three sources, namely: UNESCO institute of Statistics, Barro and Lee dataset (2013) and World Bank Data and annual growth rate of mean temperature variable is obtained from National Centers for Environmental Information (NOAA).

This research study uses secondary data, panel data has been used for availability purposes as no sufficient time series data could be collected for individual countries. In addition, both missing and unobserved variables are considered under panel estimation (Arellano and Bond,1991; Matyas and Sevestre,2013).

Measurement of the variables

In this study the dependent variable is represented by annual growth rate of gross domestic product per capita (GR_R_GDP), while independent variables are annual growth rate of female graduates from tertiary education with a ten-year lag (GR_F_TG(-10)), annual growth rate of gross fixed capital formation (GR_FC), annual growth rate of mean temperature (GR_MT), annual growth rate of gross domestic product per capita with a one-year lag are the independent variables (GR_R_GDP(-1)).

Data analysis and tools

Multiple regression analysis using ordinary least squares method was used to test the relationship between the dependent and independent variables. The used software was e-Views.

Results

A multiple regression using ordinary least squares was carried out to test the proposed hypotheses. The final model that was reached after taking into consideration multi-collinearity (no significant correlation was present between the independent variables) and heterogeneity is represented below in equation (2):

$$GR\_R\_GDP = c + \beta_1 GR\_R\_GDP(-1) + \beta_2 GR\_F\_TG(-10) + \beta_3 GR\_MT + \beta_4 GR\_FC \quad (2)$$

Table (1) below shows the estimation results of equation (2) using least squares and cross section fixed effects and period random effects methods before checking for Heteroskedasticity.

Table 1: Estimation results of equation (2) using least squares and cross – section fixed effects and period random effects.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.569126	0.247475	10.38134	0.0000
GR_R_GDP(-1)	0.233113	0.052896	4.407014	0.0000
GR_F_TG(-10)	0.012479	0.006162	2.025097	0.0439
GR_MT	0.045536	0.012131	3.753698	0.0002
GR_FC	0.050858	0.007738	6.572335	0.0000
Adjusted R^2	0.570073			
D.W stat	1.900868			
F-stats (prob.)	0.000000			

A Breusch Pagan test was run to test for heteroskedasticity in the model. The below Table (2) shows the output of the test for equation (2). It is indicated that there is a high degree of heteroskedasticity from a cross-sectional perspective since p is at a 0 while a much lower degree of heteroskedasticity is present from a period perspective where p is equal to 0.8. The high heteroskedasticity of the cross-sectional effect is accounted for through white cross-section adjustment.

Table 2: Breusch Pagan test output for equation (2)

Null (no rand. effect) Alternative	Cross-section One-sided	Period One-sided	Both
Breusch-Pagan	6.540552 (0.0105)	0.026352 (0.8710)	6.566904 (0.0104)

Note: Probability in ( )

To correct for the heteroskedasticity White cross-section adjustment was performed. Table (3) below shows output for White cross-section adjustment for estimation results of equation (2).

Table 3: White cross-section adjustment output

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.569126	0.391167	6.567847	0.0000
GR_R_GDP(-1)	0.233113	0.071927	3.240950	0.0013
GR_F_TG(-10)	0.012479	0.004709	2.649913	0.0085
GR_MT	0.045536	0.022351	2.037298	0.0426
GR_FC	0.050858	0.011295	4.502829	0.0000

Adjusted R^2	0.570073
D.W stat	1.900868
F-stats (prob.)	0.000000

The adjusted R-squared shows that the model explains 57% of the variation in the gross domestic product growth rate (dependent variable). As expected, coefficient for female tertiary graduates (GR_F_TG) with a 10-year lag, gross fixed capital formation growth rate (GR_FC) and annual growth rate of Gross domestic product with a 1-year lag (GR_R_GDP(-1)) are positive and significant at a 1% significance level indicating a directly proportional relation to the gross domestic product growth rate (GR_R_GDP). Unexpectedly, coefficient for annual growth rate of mean temperature is positive and significant at a 5% significance level, indicating a positive relationship between mean temperatures and GDP growth.

The coefficient of female tertiary graduates (GR_F_TG) with a 10-year lag, shows that when rate of female tertiary graduates increases by 1% rate of GDP growth increases by 0.012%, the 10-year lag indicates the time needed for this to take effect; this can reflect time needed for employment of educated females and might be indicative of hindrances that females in developing countries face: lack of adequate employment opportunities matching their skill set, social and cultural hinderances.

As for coefficient of gross fixed capital formation it indicates that as rate of gross fixed capital formation increases by 1%, GDP growth rate increases by 0.05%, which is justifiable since gross fixed capital formation is an indication of net investments. The small coefficient might be attributable to the fact that the sample consists of developing countries that are not always the most favourable attraction for investments especially foreign ones.

When the annual growth rate of GDP with a 1–year lag increases by 1% this leads to an increase in the annual growth rate of GDP by 0.23%, this can be attributable to the nature of the business cycle.

As for mean temperatures, when annual growth rate in mean temperature increases by 1% annual growth rate of GDP increases by 0.04% which was an unexpected result as in most of the previous literature on climate change a negative impact is usually present. Those unexpected results led to the questioning of the direction of the relationship between climate change and economic growth in this study. Accordingly, the below Granger causality test was performed to assess the direction of causality:

Table 4: Granger Causality Test for Growth rate of real GDP and growth rate of Mean Temperature (6 year – lag)

Null Hypothesis:	Obs	F-Statistic	Prob.
GR_MT does not Granger Cause GR_R_GDP	429	1.51522	0.1715
GR_R_GDP does not Granger Cause GR_MT	5.97080	5.E-06	

From the above table, it can be deduced that direction of causality is opposite to what is proposed in this study, since the null hypothesis "GR_MT does not Granger Cause GR_R_GDP" is not rejected and the null hypothesis "GR_R_GDP does not Granger Cause GR_MT" is rejected. It should be noted that the opposite direction of causality found might be due to the relatively short period studied as climate changes take place over much longer periods of time. Descriptive statistics are displayed in Table (5) below for the independent variables.

The average growth rate of tertiary female graduates is around 6.53%, where maximum growth rate is 158.9% and minimum is -50.6%. The rate of growth of gross fixed capital formation is of average 10.71%, where maximum is 129% and minimum is -81.9%. The average growth rate of annual mean temperature is around 0.42%, where maximum growth rate is 81.25% and minimum is -42.75%.

"The crucial distinction between fixed and random effects is whether the unobserved individual effect embodies elements that are correlated with the regressors in the model, not whether these effects are stochastic or not" (Greene, 2008). The cross sectional fixed effects* adjusted for annual growth rate in mean temperature coefficient for each of the 33 countries are displayed in Figure (2) below. Despite that the average coefficient for mean temperature shows a positive relationship to annual growth rate in GDP, when observing the cross-sectional fixed effects for individual countries it can be noted that countries such as Lebanon and Brazil showed a negative relation between mean temperature growth rate and GDP while other countries showed a positive one such as India. These different percentages reflect the magnitude of the possibly omitted variables that have not been included in the model given that they are assumed to be fixed and thus do not change over the years.

*The standard error for female tertiary graduate's variable was found to be bigger when applying the Hausmann test than in the regression applying both the cross-sectional fixed and period random effects, indicating that there is heteroskedasticity in the data and thus applying the Hausmann test would lead to misleading conclusions.

Table 5: Descriptive Statistics for Female graduates from tertiary education (GR_F_TG), Mean Temperature (GR_MT) and Gross fixed capital formation (GR_FC)

	GR_F_TG	GR_MT	GR_FC
Mean	6.539239	0.428504	10.71631
Median	4.793943	0.268097	8.694395
Maximum	158.9270	81.25000	129.1797
Minimum	-50.61083	-42.75862	-81.99275
Std. Dev.	15.66635	7.156826	19.40645
Skewness	2.694130	5.246404	0.925559
Kurtosis	23.00100	68.18734	7.991434
Jarque - Bera	11209.64	113891.6	740.4099
Probability	0.000000	0.000000	0.000000
Sum	4100.103	268.6718	6719.125
Sum Sq. Dev.	153642.0	32063.82	235758.0
Observations	627	627	627

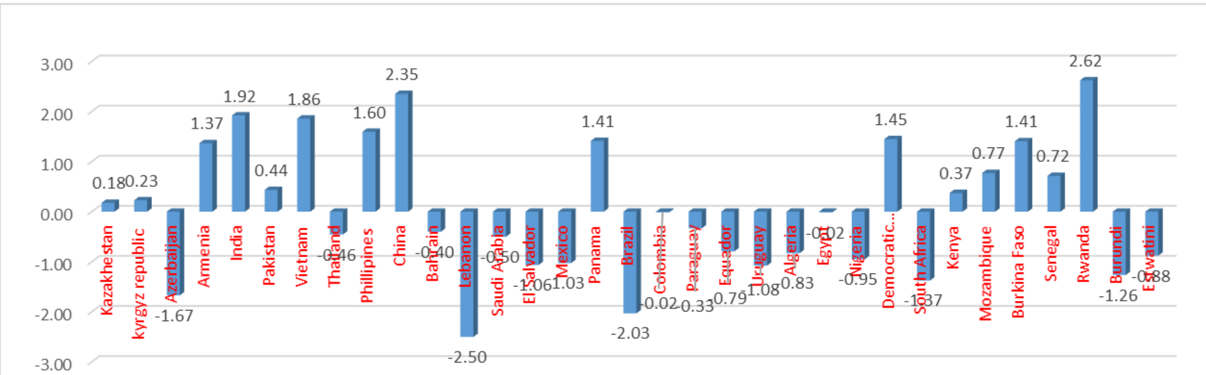

Figure 2: Percentage Effect of Annual Growth Rate of Mean Temperature on Growth rate of GDP

Discussion and Conclusion

This study helped highlight the positive and direct relationship between female tertiary education and economic growth, as well as the correct direction of the relationship between climate change and economic growth for the sample countries. The coefficient for female tertiary graduates (GR_F_TG) with a 10-year lag, the gross fixed capital formation growth rate (GR_FC), the coefficient for mean temperature (GR_MT) and annual GDP growth rate (GR_R_GDP(-1)) with a 1-year lag are all positive and significant indicating a directly proportional relation to the GDP growth rate (GDPG_C).

In previous literature (Mitra, Bang and Biswas, 2015) similar findings to our study have been found where secondary completion rate as a proxy for education was found to be positive and significant yet at an only 10% significance level where a 1% increase in secondary completion rate is accompanied by a 0.1% increase in GDP growth which is the closest results to the impact of our female education coefficient at 0.012% increase in GDP yet at a 1% significance level. The larger coefficient might be attributable to the larger number of female students enrolled in secondary education versus those graduated from tertiary education in the sample studied. Regarding investment, a positive and significant effect of 1% significance level has been found, where a 1% increase in investment increases GDP growth by 0.149% slightly higher than our investment coefficient of 0.05%. With regards to lagged growth rate of GDP the results show a significant yet negative effect where a 1% increase in GDP growth of a 1-year lag causes an 0.549% decrease in GDP growth, on the other hand this study shows a both positive and significant effect for lagged GDP of 1-year specifically an 0.23% increase in GDP. This difference might be caused by the different periods studied and the nature of the business cycle at the studied time period.

Previously mentioned results are consistent with results of (Knowles, Lorgelly and Owen, 2002) where it was found that female education coefficient is both positive and statistically significant at a 5% significance level and the t-statistic is of a 2.92 value and female education was represented by the average of schooling of the population aged 15 and above. Coefficient of female education reflects that a 1% increase in female schooling causes an 0.663% increase in output per worker, which is of a larger impact than our female education coefficient of 0.012%, although it is of a lower significance level. This difference can be due to the different periods covered: our study covers years 2001-2019 while this study covers years 1960-1990, additionally our paper uses a very specific proxy for female education, female tertiary graduates, while the study uses a much more generic proxy.

Also consistent with our study is (Klasen, 2002) where ratio of years of schooling was used as a proxy for education. Results of that study show that female-male ratio of expansion in schooling has a significant and positive effect on economic growth at a1% significance level, coefficient of female-male ratio of expansion of schooling reflects that when a 1% increase in female- male ratio of expansion of schooling occurs it causes 0.69% increase in growth of GDP, also indicating a higher impact for the coefficient when compared to our study's coefficient of 0.012% increase. Positive investment coefficient was also found to be significant at a 5% significance level, where it showed that when investment increased by 1% it reflected an increase of 0.056% in GDP, identical to our study's coefficient of 0.05% increase in GDP, yet of a higher 1% significance level.

Our results were parallel to previous literature (Baliamoune-Lutz and McGillivary, 2009) where the gap in youth literacy between females and males had a negative and significant impact on income, where Coefficient for gap was significant at a 1% significance level, where a 1% increase in the gap causes a 0.2% decrease in income growth reflecting a higher impact on income growth than our study does at 0.012% percentage change in GDP. The coefficient of investment was both positive and significant at a 1% significance level where a 1% increase in investment caused an increase in income growth ranging between 0.13 - 0.16% again compared to this study's coefficient of 0.05% it is of relatively larger impact.

On the other hand, our findings were inconsistent with (Oztunc, Oo and Serin, 2015) where female tertiary education is negatively related to annual GDP per capita growth, where GDP decreases by 1 unit when tertiary female education is increased by 10 units reflecting an influence of 10 % of female tertiary education on GDP per capita. We believe the reason for the contradiction to our results is the nature of jobs available in the sample countries in this specific study where it was stated that most jobs for female workforce are unskilled labor jobs and thus obtaining a tertiary education is deemed unnecessary. Another finding that was inconsistent with ours is (Licumba et al., 2015) that used human capital as a proxy of education found that with a two-year lag it was both negative and insignificant for growth. Again, contradiction to our results here may have originated from the fact that the sample under study was restricted to 5 Southern African countries and the proxy was primary enrolment.

With regards to our climate change proxy variable, annual growth rate in mean temperature has a positive and a 5% significance level coefficient reflecting the direct relationship to GDP growth rate, which is contradictory to what previous literature highlighted where climate change had a negative impact in most cases (Eboli et al., 2010; Solomon et al., 2017) or no significant impact was observable from an aggregate worldwide perspective (Newell et al., 2021). This study's unexpected results led to rethinking the direction of the relationship and conducting the previously mentioned Granger Causality test to deduce that the results are significant, yet the relation should be tested in the opposite direction. Another recommendation would be to increase the time period studied and to test for the direction of the causality again.

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Exploring the factors affecting consumers’ willingness to purchase alternative fertilisers in the UK

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Extended Abstract

The UK population increased to 66.8 million in 2019 (ONS, 2021), making it crucial for agriculture and farmers to meet the demand for produce while limiting the negative impact on the environment due to intensive farming and fertilisers use. Therefore, prioritising sustainability has been the goal for the farming community and the environmentally aware consumer. In this regard, DEFRA (2021) is promoting alternative fertilisers (AF), and consumers now appear more positively inclined towards them. Specifically, in recent years, the popularity has increased towards AF such as chicken manure pellets (CMP), sheep’s wool pellets and digestate in agriculture and the horticultural market due to high consumer demand.

On the side of horticulture, the trend of adopting AF is followed with evidence supporting that 67% of UK gardeners claim to be eco-conscious and 46% stating that they are already using organic fertilisers. This is reflected in the figures provided by the UK Organic Market Report in 2020 revealing that the market has seen a growth in the past eight years whereas in 2019 a 4.5% increase has been recorded in sales reaching £2.45bn. During the covid-19 pandemic, the UK horticultural sector saw a substantial increase in gardening equipment and seeds sales. During the peak of the 2020 lockdown, sales were reportedly 20 times higher than 2019 (Perrone, 2020). This is due to the trend observed from an increased number of consumers who grew their own vegetables and fruits during the lockdown periods. This aligns with the increase seen in environmental awareness amongst UK consumers in 2021 with 85% now making more sustainable lifestyle choices (Deloitte, 2021). In this sense, the term “eco-conscious” has been widely used to describe an individual who shows concern for the environment. This increased awareness has led horticultural consumers to seek for AF such as CMP due to their effectiveness as a non-CF and valuable nitrogen source for plants to grow green leaves.

However, there is limited evidence regarding the factors influencing consumers' willingness to purchase AF in the UK, and in particular CMP. Previous literature showed a gap into studies exploring the sector including a lack of domestic research on AF, a scarcity of consumer research on AF, and a lack of information on CMP. The limited evidence found on AF could be attributed to the fact that the concept is relatively new and there are few AF available to the market. Thus, the present study attempts to fill in this knowledge gap and to contribute to existing literature regarding consumers’ views and purchase attitudes towards AF and CMP. Gaining an understanding of these factors can assist in proposing strategies that could induce the demand for AF by targeting some of these factors. Therefore, results have the potential to induce beneficial environmental behaviour that can contribute to Net Zero. To this respect, the present study explores consumers’ perceptions and attitudes affecting consumer

intention to purchase CMP as AF. In addition, the factors affecting consumers' intention to purchase CMP as AF are explored and the level of the awareness regarding the benefits of CMP as AF is evaluated. This is pursued using the Theory of Planned Behaviour (TPB) expanded with more variables that may influence the purchase behaviour. TPB was proposed by Ajzen (1985), who estimated that the subjective norm, perceived behavioural control, and attitude influence intention to purchase, which in turn affects actual behaviour. A semi-structured questionnaire was created and distributed online in different social media accounts whereas snowball and convenience sampling techniques were employed. The questionnaire was composed of both open and closed ended questions such as binomial dichotomous questions and 5-point Likert scale questions. The first section of the questionnaire included demographic questions to create the profile of the participants as well questions related to consumers' perceptions regarding AF and the benefits arising from the usage of AF were included and the level of awareness and knowledge towards sustainability goals, AF and CMP was examined. The next section involved questions related to fertiliser characteristics that may affect the purchase along with subjective norm influences and 5-point Likert scale statements examining the willingness to purchase CMP as AF. Prior to the data collection, a pilot survey was conducted to 10 consumers allowing for minor spelling corrections to be made whereas the final questionnaire was open for two weeks and results to 180 responses to be gathered. Data was presented using descriptive statistics and inferential statistics employed included the Spearman correlation analysis to identify relations between ordinal variables and multiple regression analysis using backward Wald to explore significant causal relations between the purchase intention and the factors that impact it. Moreover, Mann-Whitney U test and Kruskal Wallis H test detected significant differences across the participant demographics on the median willingness to purchase AF (Cronk, 2018). Principal Component Analysis (PCA) was used to reduce the number of variables and the reliability of the new components was tested with Cronbach alpha coefficient where 0.7 and higher indicated high reliability levels (Pallant, 2010). In terms of qualitative data, these were coded and analysed using thematic analysis to detect patterns across the respondents.

Results showed that the most important element influencing consumers' willingness to buy CMP was its nutritional content. This demonstrates consumers are concerned about CMP's low NPK value compared to CF' and multiple soil benefits associated to its use (Byju's, 2022). To a lesser extent, price influenced buyers' intention followed by alternative fertiliser made from animal by-products; smell was least influential. Consumers were willing to pay less for CMP compared to CF as also supported by the lower market prices. This attitude may be explained by the products 'introduction' stage and time needed to be established in the market (Taisch et al., 2011). Cheaper introductory prices would gain consumers interest, increase purchase intention, and therefore demand and prices (Estelami and Bergstein, 2006). This was also supported in the results where consumers who showed a higher level of trust in CMP over CF exhibited a higher purchase intention. Also, preference towards AF made from animal-by-product could be explained by the pasteurization process undertaken by manufacturers making products safer to use (Tur-Cardona et al., 2018). Although the volatilization process creates a strong odour due to ammonia discouraging many consumers from purchasing CMP, smell played a neutral role to purchase intention in this survey. This could be due to most participants residing in rural/semi-rural areas and being involved in the agricultural sector; thus, being more familiar to this odour. Consumers' purchase is mainly affected by the products quality, then safety and sustainability attributes, because consumers expect a level of safety when purchasing CMP products. The products quality is important to consumers as this maintains their loyalty leading to an increase in profitability (Wiengarten and Pagell, 2012). In addition, consumers perceive CMP as effective which may be linked to the perception that it slowly releases nutrients into the ground. CMP slow release over a period of three months helps root development and encourages overall plant health leading to better overall growth (Purnomo et al., 2017). Lastly, a preference towards CMP made in the UK rather than abroad was supported. This could be due to the UK importing most of its CMP from EU countries, predominately Netherlands. The implications of import tariffs caused by Brexit has promoted supporting local, empowering the UK economy, and saving money on import tariffs. There were multiple factors seen to affect consumers' intention to buy CMP as supported by regression analysis. These included trust, lower price than chemical fertiliser, external factors, prior awareness, and price. Product trust had a positive significant impact on purchase intention with increased trust leading to increased purchase. If consumers trust a product or service they invest more and are willing to spend more on this product (Woolley and Fishbach, 2017). CMP'S Lower price than CF had a positive impact on purchase intention. This is explained by consumers' confidence in a product; as CMP is new to the domestic market, consumers are willing to try it but only if cheaper than a product they trust (KUMAR, 1996).

External factors had a positive impact on purchase intention e.g., goals set by the government for the country. This is explained by an increase in eco-friendly consumers from a culture change in consumers wanting to look after the environment (Popovic et al., 2019). Product prior awareness had a small positive impact on purchase intention; with increased prior awareness consumers are more likely to purchase it over competitors' products, as they have a better understanding of the product, what it offers over competitors and increased trust levels (Rao and Monroe, 1988). The final factor was price which played a negative impact on purchase intention as increasing a products price means consumers are more likely to change to a competitor. This is explained by higher priced products selling fewer units, leading to competitors products becoming more appealing if they can offer the same purpose at a cheaper rate (Zhao et al., 2021).

Participant demographics were not found to affect CMP purchase intention. This could be explained by the fact that traditionally older demographics were more interested in gardening. An increase however has been seen in younger gardeners due to several reasons including climate change, Brexit and producing more food in the UK (Sia et al., 2022). There were multiple levels of awareness regarding the benefits of CMP as AF. The participants who studied in the agriculture sector were most likely to purchase CMP possibly because they can understand that CMP offers overall more value in the form of macro and micronutrients and soil health than CF can offer (Hoover et al., 2019). Also, the level of awareness about CMP's benefits as an alternative fertiliser was influenced by environmental consciousness. 74 participants said they were environmentally conscious, indicating a significant increase in environmental care. This is explained by the government's and other companies' increased efforts to set net zero goals for the public to strive for through their purchasing habits and behaviour.

Based on these results, when companies are marketing AF such as CMP, it is important to emphasise other beneficial features besides the NPK value, such as improved soil health. Government could also focus on the advantages of utilising AF by linking their use to UK net zero targets. Policy makers should subsidise research into the effects of AF on the horticultural industry. There were some limitations associated to the study which affected the overall results including sample size, data availability, sampling techniques and time frame. Thus, further research could of interviews to gain an in depth understanding of consumers thoughts on adopting AF over CF.

Keywords

Alternative fertilisers; net zero; sustainability

Presenter Profile

Dr Eric Siqueiros works as Innovation Manager for the European Regional Development Fund project AGRI at Harper Adams University since 2018. He is also a lecturer for the Food Land and Agribusiness Management Department. His main interests are in developing processes and strategies for the sustainability metrics of the Food and Agricultural Sector. Eric holds a PhD focused in Sustainable Energy and Waste Recovery from Newcastle University. In recent years he has been working with sustainability assessment tools for farm management as well as Life Cycle Assessment of different crop systems.

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Factors affecting farm business resilience

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Abstract

Direct payments under the Basic Payment Scheme (BPS) will be phased out in England by 2027, with some 38% of farm businesses having costs that exceed revenue when direct payments are excluded (AHDB, 2021). Furthermore, 48% of farmers indicate that the loss of BPS will have biggest impact on business going forwards (DEFRA, 2021). Post-BREXIT international trade negotiations between the UK and the EU and other countries have added more uncertainties for British farmers. To cope with the changing economic and institutional conditions, resilience thinking is on the top of agenda in policy making. Meuwissen et al. (2019) regarded farm resilience as capacities of robustness, adaptability, and transformability in the face of economic, environmental, social, and institutional shocks and stresses.

This study aims to explore English farmers' perceived business resilience and its influencing factors based on 1769 responses obtained during September 2021 to May 2022. The survey questionnaire included 20 statements to measure perceived farm business resilience in addition to farm key performance indicators, farmers' attitudes about future of farming and socio-demographic attributes of the farmers and their farms.

The study found that nearly 40% of the farmers were "resilient" or "very resilient". Younger farmers, tenant farmers, and full-time farmers reported a higher level of business resilience than other groups. The 65 and over age group, farmers with mixed ownership status or part-time farmers reported the lowest level of business resilience. Dairy and cereal farmers reported the highest level of resilience, whilst livestock farmers, particularly LFA livestock farmers reported the lowest level of resilience on average. Confidence in responding to changes, farm performance, farm size and having information to inform business planning were the most important predictors of farm business resilience.

Keywords

Farm resilience; loss of Basic Payment Scheme (BPS); Farmers in England; Predictors of farm resilience.

Presenter Profile

Dr Iona Yuelu Huang is a senior lecturer at Harper Adams University. She has been a member of several research teams, including AgroCycle (a Horizon 2020 funded project on valorisation of agri-food waste) and the Newton Fund Institutional Links project "Sustainable Agribusiness Model for Poverty Reduction among Thai Small-scale Rubber Farmers". Her research interests fall into the broad categories of food waste management, governance of supply chain, agribusiness decision making and economic impact of agri-tech and innovation adoption.

Estimating Biomass Carbon stocks in Agriculture Land for the Mediterranean using remote sensing data

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Abstract

Climate change has a crucial impact on European agriculture in plenty of ways. The role of land use systems, such as agriculture, as a climate change mitigation and adaptation strategy is important as these systems can collect atmospheric carbon dioxide (CO2) and store carbon (C). Although biomass carbon storage in agriculture has been highly neglected. The methodological difficulties in estimating the C stock of biomass and soil storage of Carbon are reinforced by the lack of reliable estimates of the agriculture area. This research analyses the relationship between changes in tree cover in agricultural areas of the Mediterranean area (more specifically in the regions of Spain, Italy and Greece) and the storage of biomass carbon (associated with the related mitigation of CO2 emissions). Remote sensing images have become a valuable source of data for this analysis. A set of remote sensing data with MODIS satellite images was used and was combined with Tier 1 carbon storage estimates to estimate carbon dioxide storage for the Mediterranean climate zones. The measurements for biomass carbon were made at the overall level for the Mediterranean but also separately for the national and regional levels of Italy, Greece and Spain. The findings of the research showed that the distribution of tree cover in agricultural areas widely followed the climatic zones. Most part of the agricultural land in Europe is estimated at levels around 10 t C / ha.

Keywords

Carbon stocks, agricultural land, MODIS satellite images, biomass, tree cover

Presenter Profile

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Introduction

Agriculture is a key sector as far as is concerned climate change. The main causes of climate change are the greenhouse effect and global warming. Global warming, the rise in the temperature of the Earth's atmosphere and oceans, is believed to be mainly due to rising atmospheric concentrations of so-called Green House Gases (GHG), and carbon dioxide (CO2) is a major GHG (Nair et al., 2009). Global land use change contributes to the effects of climate change. Climate change requires measures to reduce greenhouse gas emissions and adapt them globally and regionally. Agriculture is a factor that contributes significantly to climate change but has the potential to reduce climate change. Changing land use in agriculture and agricultural production has contributed and continues to contribute significantly to the effects of global warming. Agriculture and tree cover have the potential to alleviate climate change. Agricultural production and land use change significantly affect greenhouse gas (GHG) emissions (Zomer et al., 2016). To slow down the effects of climate change, greenhouse gas emissions must be reduced. Carbon dioxide (CO2) is the greenhouse gas most produced by human activities and is responsible for 63% of global warming due to these activities. Various factors determine the complex relationship between the influence of greenhouse gas emissions and the concentration of these gases in the atmosphere. However, there are two strategies available to mitigate CO2 growth: reducing emissions or increasing atmospheric CO2 uptake by plants through photosynthesis thus increasing biomass in terrestrial ecosystems (Zomer et al., 2008).

The global role of tree-based carbon sequestration on agricultural land has not been well understood and may have been significantly underestimated. According to the European Commission (2018), 16% of the current Mediterranean area is likely to become barren land by the end of the century and in many southern European countries, the productivity of rural work is to be reduced by 10-15% compared to current levels. Agricultural forestry (agroforestry) is often discussed as a strategy that can be used to both adapt to and mitigate climate change (Zomer et al., 2016). One of the approaches to reducing the concentration of CO2 in the atmosphere is the capture of carbon (C), the process of removing C from the atmosphere and depositing it in a tank (Nair et al., 2009; Ramachandran Nair et al., 2010). While the importance of biomass carbon in forests (above and below ground) is widely recognized, the biomass carbon reservoir on agricultural land is negligible. For these reasons, there is a suitable ground for investigating the carbon uptake of biomass in agricultural land (Smith, 2012).

The present study aims to assess the importance of trees in agricultural areas and their contribution to the Mediterranean lands for the capture of biomass carbon. This analysis concerns the Mediterranean region and more specifically estimates the biomass carbon at national and regional levels for the Mediterranean countries (Italy, Spain, Greece) and Europe as a whole. In addition, a comparison was implemented for the time periods 2000-2018 for the existence and detection of changes and to be pinpointed spatial patterns both within the country but also between countries and regions. These calculations were based on IPCC Tier 1 default estimates of carbon stored in different land types and bioclimatic zones and were combined with tree cover data based on MODIS satellite remote sensing images.

Methods

Remote sensing techniques have many advantages in estimating above ground biomass over traditional field measurement methods and provide the ability to estimate biomass at different scales, using either linear or non-linear regression models (Houghton, 2005; D. Lu, 2005; Dengsheng Lu, 2006; T. Vashum, 2012). Remote sensing images can be used to estimate biomass above ground in at least three ways: classification of vegetation cover and mapping of vegetation type, indirect estimation of biomass through some quantitative relation (regression equations, NDVI, etc.), dividing the spatial variability of vegetation cover into relatively zones or classes, which can be used as a sampling frame for soil identification and measurements (Ponce-Hernandez, 2004). Although there are no practical methods for directly measuring all forest carbon stocks in a country, both terrestrial measurements and remote sensing data on forest characteristics can be converted into estimates of national carbon stocks using allometric relationships and Optical satellite data systems (MODIS, Landsat, SPOT) commonly used for deforestation detection and can detect changes in forest area more accurately (Gibbs et al., 2007; West et al., 2010).

The research methodology which is followed in this study is based on the methods of the scientific article of Zomer et al. (2016). This study was undertaken to investigate the significance of agricultural land for carbon sequestration and to mitigate the effects of climate change in the Mediterranean zone. Estimating the carbon biomass; The first step was to be found the percentages of tree cover in the agricultural land. To estimate the percentage of tree cover only in agricultural areas, a set of remote sensing data with MODIS satellite images from 2000 to 2018 was used and combined with the Global Land Cover 2000 database (GLC 2000) to export only categories belonging to agricultural land. The data used to perform this procedure are as follows:

- MOD44B MODIS / Terra Vegetation Continuous Fields Yearly Global 250m - Collection 6 (2000 through to 2018):
- Percent Tree Cover
- Global Land Cover 2000 (GLC 2000) Database • Land-cover categories

Tree coverage has been recorded from the VCF-Collection 6 data set for the years 2000 - 2018, because the time period covered by the study is almost 20 years and to reduce the impact of this variability on the estimates of change during period and in order to the results are more reliable, the first three years of the data set (2000-2002), the three years (2008-2010) and the last three years (2016-2018) were calculated on average. In this way, the 3-year average for the different time periods was used to analyse the changes. In addition, three types of agricultural uses from the Global Land Cover 2000 land use database were used to export the categories belonging to agricultural land, which are the following:

- Cultivated and Managed Areas (agriculture - intensive),
- Cropland / Other Natural Vegetation (non-trees: mosaic agriculture / degraded vegetation)
- Cropland / Tree Cover Mosaic (agriculture / degraded forest)

With the help of ArcGIS software and after calculating the three-year average for the percentage of tree cover, the pixels were extracted for all three years (2000, 2010, 2018) where they belonged to the categories defined as agricultural land. Then, using the percentage of tree cover only for the agricultural land, the carbon estimates of the biomass in the specific areas were calculated. To quantify biomass carbon estimates on agricultural land, the default IPCC Tier 1 biomass carbon estimates stored in different types of soil cover depending on the climatic zones located and combined with the ground cover estimates were used. According to the IPCC Guidelines of 2006 (Chapter 5, section 5.2.1) changes in carbon in cultivated areas that remain in the same land use category can be estimated either by: (a) annual growth and loss rates of biomass or by (b) carbon stocks at two time points, depending on the Tier method used.

The "New Global Tier-1 Carbon Map for IPCC Tier-1 for the year of 2000" (available from the Carbon Dioxide Information Analysis Center (CDIAC) Oakridge National Laboratory) was used for global Tier 1 biomass estimates (Ruesch & Gibbs, 2008) synthesized and mapped the default IPCC Tier-1 values using a global land cover map stratified by continent, ecosystem, and forest disturbance, and aggregated a total of 124 carbon zones or areas with unique deposit values based on IPCC Tier-1 methods. In order to take into account the added contribution of tree cover to agricultural land, the default value of category 1 biomass carbon for agricultural land (5tC / ha) was used as the base value, when there are no trees in this area (tree cover = 0%), regardless of the climatic zone located receives a biomass carbon value of 5 tC / ha.

For the calculation of biomass, the percentage of tree coverage was divided according to the climatic zone (carbon zone) to which it belongs. In the context of this dissertation, the values for the Mixed Classes Forests (GLC2000 Classes 6-¬8) for 5 climate zones were used for Europe by the New Global Tier-1 Carbon Map for IPCC Tier-1 for the year of 2000 which are the following:

- Subtropical Dry Forest
- Subtropical Mountain Systems
- Oceanic Forest Temperate
- Continental Forest Temperate
- Temperate Mountain Systems

According to the climate zone and the default carbon value obtained by the above climate zones according to the table from the New Global Tier-1 Carbon Map for IPCC Tier-1 for the year 2000 a linear increase of biomass carbon from 0% was calculated up to 100% tree coverage depending on the climatic zone to which it belongs. Practically, using as a basis the percentage of tree cover for each year was reclassified in tC from the minimum value of 5t C / ha to the maximum value obtained by biomass carbon in the 5 different climatic zones used, biomass carbon values in agricultural areas if there is 100% tree coverage is equal to the relative price for Mixed Forest Classes, in each climate zone. The results of the estimates were calculated in tC / km2 and then converted to t C / ha. In addition, the difference in the carbon level of biomass was calculated both for the decade 2000-2010 and for almost twenty years from 2000-2018. For the calculation of biomass carbon for each country and its regions, the geographical-administrative limits of Eurostat - Nuts 2016 were used. The calculation both at country and region level was done in t C / km2 and then converted to tC / ha.

Results

Areas that are either non-agricultural or urban areas have been excluded from the tree cover data. The area of agricultural land has been stratified for each value of tree cover from 0 to

100. The Mediterranean countries seem to have a low rate of tree cover up to 15%, a pattern that is followed over time for all 3 years under consideration. Over a period of almost twenty years (2000-2018), most European countries have low to moderate tree cover rates (10% - 30%) on agricultural land. Nevertheless, between years 2000 - 2018, there is a small decrease of 2% of the tree coverage both between 2000 - 2010 and 2010 - 2018. More specifically, 82%

was the maximum value of the percentage of tree cover in 2000, in 2018 the maximum value is at 78%. Over time, as shown in Figure 1, in Europe the percentage of tree cover in almost twenty years (2000-2018) shows a decrease of up to -8% while the difference in the percentage of tree coverage shows values from -72% to + 65%. In addition, it is found that a small part of Greece and Italy show an increase of up to 15%. Between the years 2000-2018, Europe has a low rate of tree coverage of up to 20%, a fact that is a following pattern in the Mediterranean countries as well.

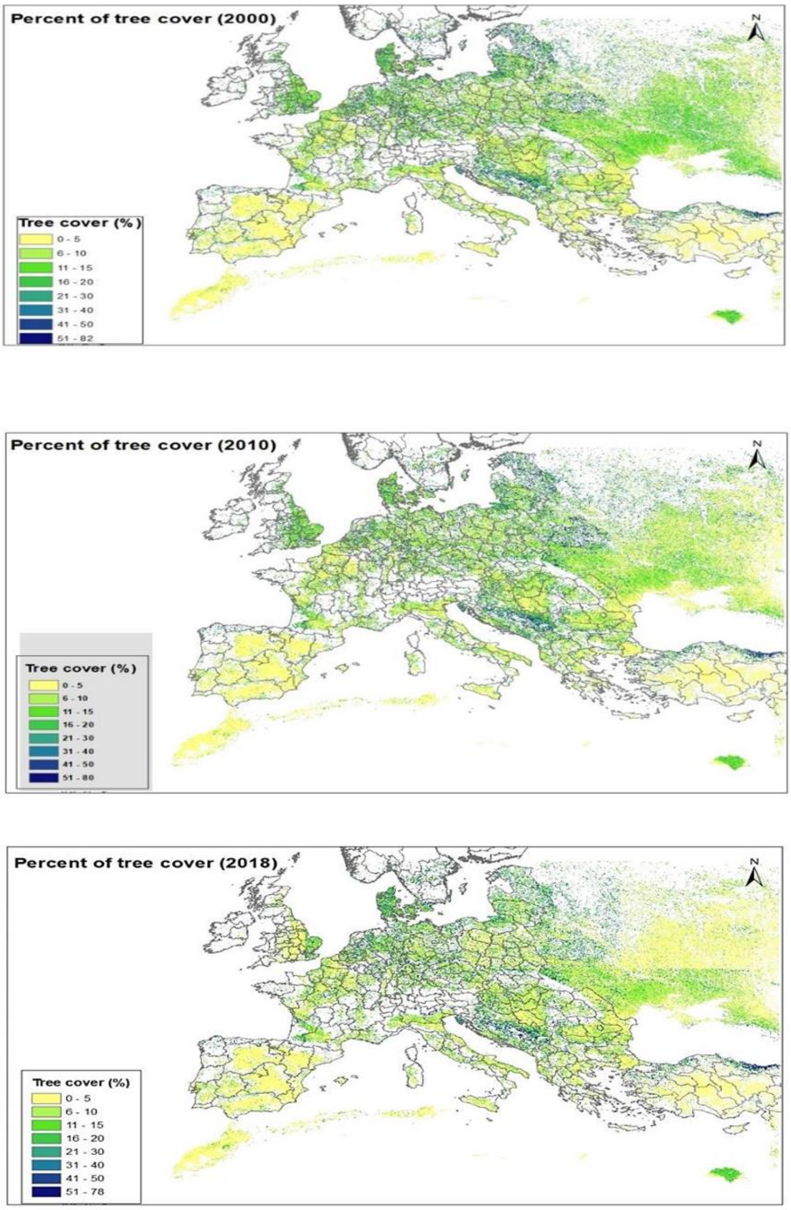


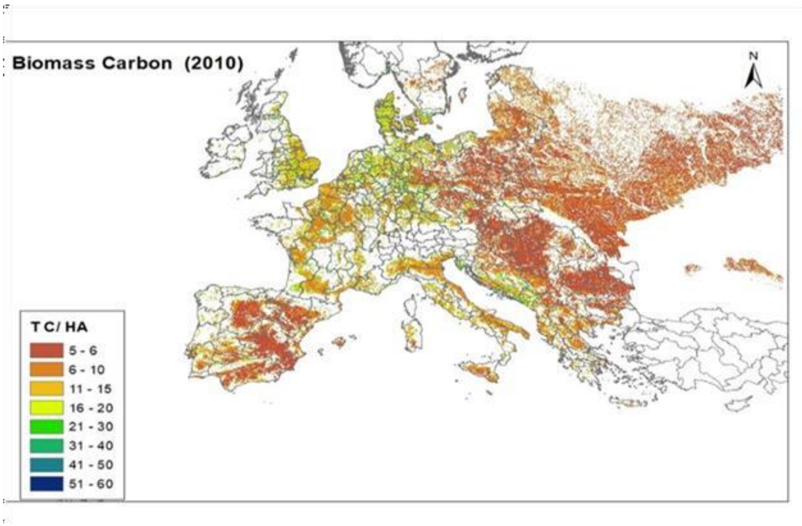
Figure 1: Percent of tree cover in agricultural areas for the years 2000, 2010 and 2018 respectively and change in the percentage of tree cover for the years 2000 – 2018.

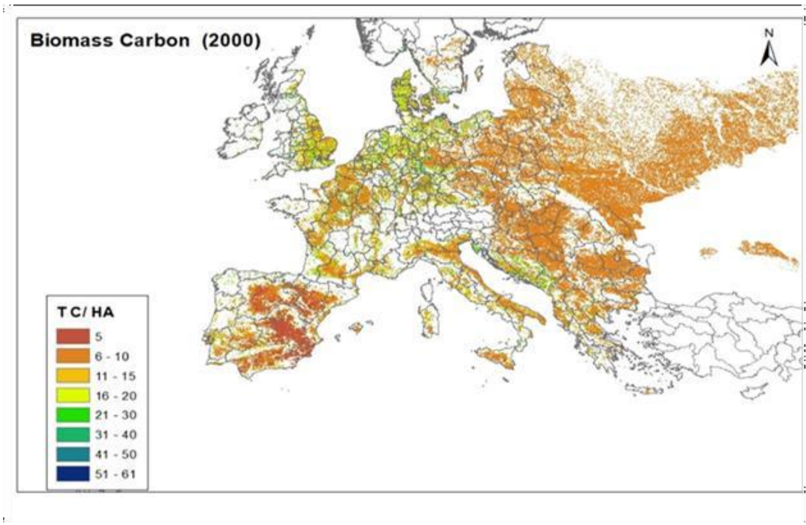
Europe shows a low reduction in biomass carbon, this same pattern is followed and comparing the changes between the years 2010-2018 and 2000-2018 (Table 1). However, observing the changes from 2000 to 2018, it seems that Greece, Spain and Italy have an increase in biomass carbon levels.

Table 1: Average biomass carbon (tC / ha) for the years 2000, 2010 and 2018 and changes in Mediterranean countries and Europe.

Average Biomass Carbon (t C/ha)

Country	2000	2010	2018	Change (2000-2010)	Change (2010-2018)	Change (2000-2018)
Spain	7,5	7,71	7,9	0,21	0,19	0,4
Italy	11,05	11,45	11,39	0,4	-0,06	0,34
Greece	9,05	10,54	10,77	1,49	0,23	1,72
Europe	**9,14**	**9,08**	**8,86**	**-0,06**	**-0,22**	**-0,28**





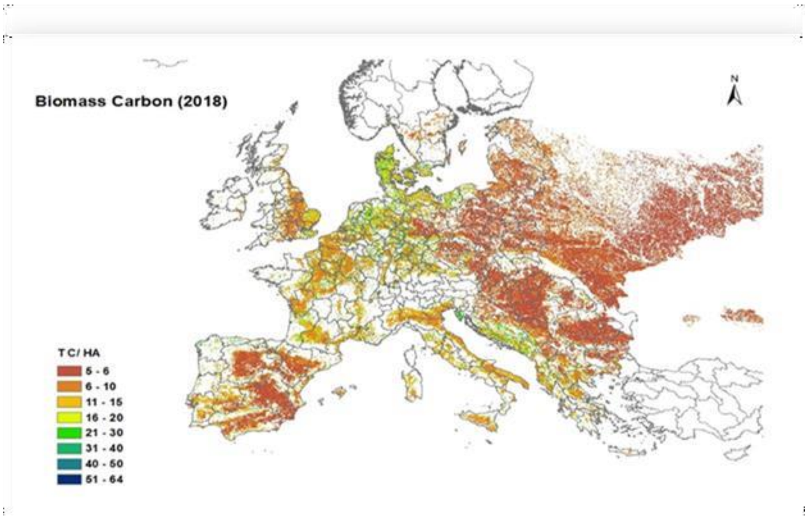


Figure 2: Biomass carbon for the years 2000, 2010 and 2018

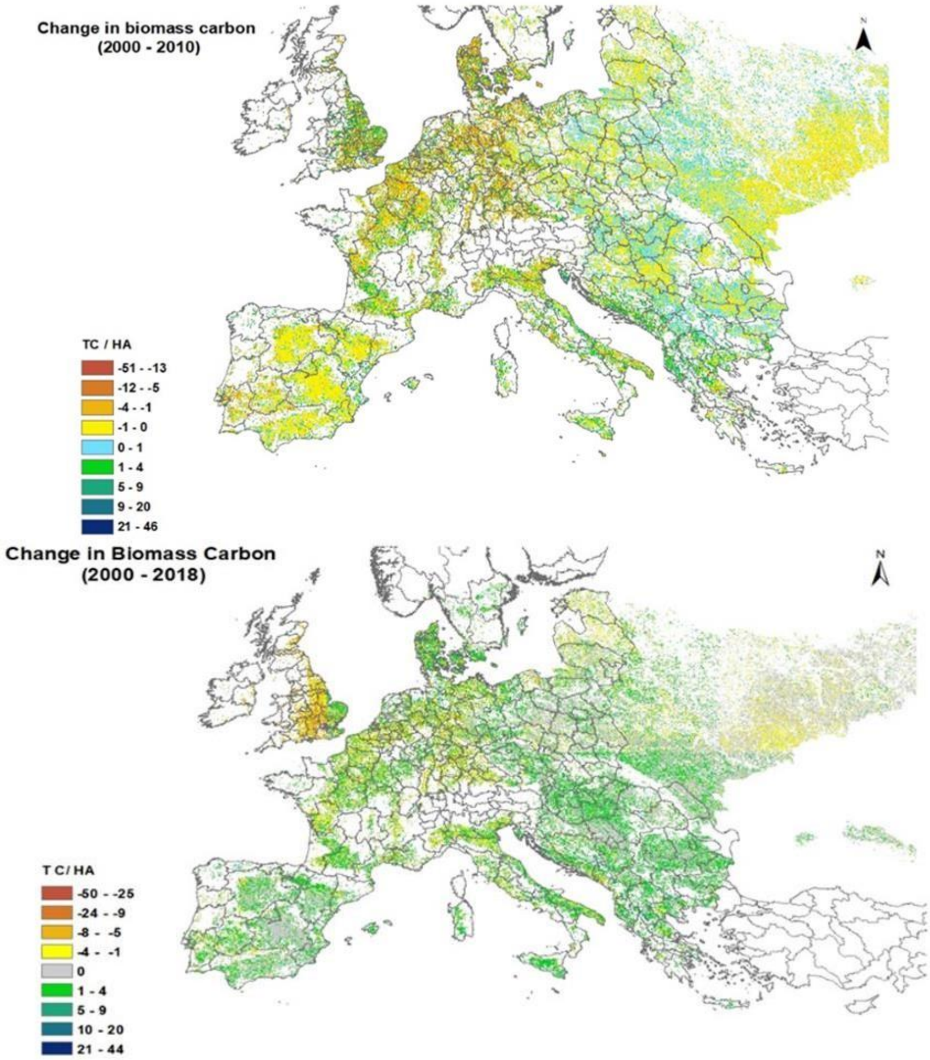


Figure 3. Change of biomass carbon between the years 2000 - 2010 and 2000 - 2018 respectively

Comparing the biomass carbon of the Mediterranean regions with the European average is observed that 16 of the 56 Mediterranean regions are below the European average in 2000.

More specifically, 11 of these regions are Spanish (see table 2 and Figure 3), 4 of these regions are in Greece while the only Italian region is Sicilia which is presented below the European average. The same pattern with slight differences seems to follow in 2010 as 16 regions are below the European average. The same 4 Greek regions (Attica, North Aegean, South Aegean, Eastern Macedonia and Thrace) continue to be lower than average, the Italian region of Sicilia is the only one of the Italian regions that in 2010 has lower biomass carbon levels from Europe. Spain follows similar patterns with 9 regions at lower levels than Europe. Apart from the regions of Illes Balears and Comunidad Valenciana which are at higher levels than Europe in 2010. In 2018, 12 regions are at lower levels of biomass carbon than the European average but none of the regions of Italy. The regions with the lowest levels belong to Greece and Spain; 4 of them are Greek and the remaining 8 are Spanish.

Table 2: Average biomass carbon (tC/ha) for the years 2000, 2010 and 2018 and its change

		Average Biomass Carbon (t C/ha)			Change in Biomass Carbon (t C/ ha)		
Regions	**Code**	**2000**	**2010**	**2018**	**(2000 -2010)**	**(2010-2018)**	**(2000 -2018)**
Attica	EL30	6,1	7,0	8,0	0,9	1,0	1,9
North Aegean	EL41	10,7	11,4	11,6	0,7	0,2	0,9
South Aegean	EL42	6,2	7,0	7,2	0,7	0,3	1,0
Crete	EL43	7,2	7,2	8,4	0,1	1,2	1,3
Eastern Macedonia and Thrace	EL51	7,6	8,7	8,6	1,2	-0,1	1,0
Central Macedonia	EL52	9,1	10,9	10,7	1,7	-0,2	1,6
Western Macedonia	EL53	9,2	12,1	12,6	2,9	0,5	3,4
Epirus	EL54	11,4	14,9	14,3	3,5	-0,6	2,9
Thessaly	EL61	9,1	10,2	10,6	1,1	0,4	1,5
Ionian Islands	EL62	10,0	10,4	11,4	0,4	1,0	1,4
Western Greece	EL63	11,0	11,4	11,4	0,4	0,0	0,4
Central Greece	EL64	9,4	10,0	11,2	0,6	1,2	1,8
Peloponnese	EL65	9,8	10,6	11,2	0,8	0,6	1,4
Galicia	ES11	19,4	22,6	22,9	3,2	0,3	3,5
Principado de Asturias	ES12	21,6	22,6	24,7	1,0	2,1	3,1
Cantabria	ES13	17,1	17,8	18,0	0,7	0,2	0,9
Pais Vasco	ES21	10,7	11,1	11,5	0,3	0,4	0,8
Comunidad Foral de Navarra	ES22	7,9	8,2	9,0	0,3	0,8	1,1
La Rioja	ES23	7,5	7,7	8,1	0,2	0,4	0,6
Aragon	ES24	6,8	7,1	7,2	0,4	0,1	0,4
Comunidad de Madrid	ES30	7,1	7,1	7,3	0,0	0,3	0,2
Castilla y Leon	ES41	7,2	7,1	7,3	-0,1	0,2	0,1
Castilla-La Mancha	ES42	6,4	6,5	6,6	0,1	0,1	0,2
Extremadura	ES43	8,9	8,0	9,1	-1,0	1,1	0,1
Cataluna	ES51	9,3	9,8	9,7	0,5	-0,1	0,4
Comunidad Valenciana	ES52	7,5	9,5	8,5	1,9	-1,0	0,9
Illes Balears	ES53	8,1	9,4	9,6	1,4	0,2	1,6
Andalucia	ES61	7,6	7,5	7,8	-0,2	0,4	0,2
Region de Murcia	ES62	5,5	6,0	5,9	0,5	-0,1	0,3
Piemonte	ITC1	12,3	11,7	11,1	-0,6	-0,6	-1,2
Liguria	ITC3	19,0	21,9	20,1	3,0	-1,8	1,1
Lombardia	ITC4	11,4	11,2	11,1	-0,2	-0,1	-0,3
Abruzzo	ITF1	10,4	12,5	11,8	2,1	-0,7	1,4
Molise	ITF2	10,0	11,6	12,2	1,5	0,6	2,1
Campania	ITF3	12,0	13,6	13,1	1,6	-0,5	1,1
Puglia	ITF4	9,3	9,4	9,8	0,1	0,4	0,5
Basilicata	ITF5	9,7	10,8	11,2	1,1	0,4	1,5

Conclusion

The distribution of tree cover in agricultural areas widely followed the climatic zones. Mediterranean countries seem to have a low rate of tree cover up to 15%, a pattern followed over the years analysis (2000 - 2018). Between the years 2000-2018, Europe has a low percentage of tree cover up to 20%, a fact that is strongly prominent in the Mediterranean countries. The percentage of tree cover in the Mediterranean presents small percentage changes from - 8% to 6% between the years 2000 - 2018. As far as concerned biomass carbon, most agricultural areas have fairly low to moderate levels of biomass carbon. Most agricultural land in Europe is estimated at levels below 10 t C / ha. Mediterranean countries show an increase in biomass carbon in 2018 compared to the initial year 2000. In addition, Italy and Greece are at higher levels than the European average. Greece and Italy seem to have the largest increases in biomass carbon stored on agricultural land. At the regional level in the last twenty years (2000-2018) positive elements are identified as most of the Mediterranean regions have an increase in biomass carbon levels compared to 2000. The growth levels for the regions range from 0.1 - 3, 5 t C / ha. On average, the Mediterranean regions in the variable of biomass carbon per hectare in agricultural land follow an increasing trend of up to 3 t C / ha from 2000 to 2018. All regions of Greece and Spain have an increase in biomass carbon compared to 2000. This a trend that does not seem to be followed by the Italian regions.

Climate change is having an impact on European agriculture in several ways. Slowing down soil degradation and enhancing carbon sequestration on EU soil is a win-win climate and food security strategy that reduces CO2 emissions while increasing the fertility and productivity of EU agricultural land (Jacobs et al., 2019). The EU Climate Change Adaptation Strategy and the Common Agricultural Policy have enabled adaptation actions in the agricultural sector. The Common Agricultural Policy (CAP) constitutes the main framework of the European Union's agricultural policy. Policymakers can implement the potential of agroforestry as a strategy and a key component both for the adaptation and mitigation of climate change. Biomass carbon on agricultural land deserves attention for its mitigation potential.

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Sustainable Urban Resilience: Cities in the face of modern challenges. Case study: The city of Elliniko-Argyroupoli, Greece

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Abstract

The present paper deals with the analysis of the current situation of the Municipality of Elliniko - Argyroupoli, in the region of Attica in Greece, regarding the sustainable urban resilience to impending disasters. The disasters are divided into natural and technological, of which natural disasters have affected the Municipality of Elliniko - Argyroupoli in recent years. Climate change, the increasing trend of urbanization, and the city's complexity are among the main reasons that necessitate urban resilience to prevent, respond to, and recover from a variety of impending disasters. The operational plans for civil protection, combined with the sustainable urban mobility plans and the waste management plans of the Municipality of Elliniko - Argyroupoli, make it a model municipality for achieving urban resilience. Through the results of the questionnaire, conclusions are drawn that could be considered useful both for the further analysis of the current situation and for the design of future policies.

Keywords

Sustainable urban resilience, Municipality of Elliniko – Argyroupoli, fractures, city resilient

Presenter Profile

Roido Mitoula is Professor at Harokopio University of Athens. She has scientific publications and has participated in numerous Greek and international Conferences. She specialises in issues of "Local and Regional Development - Urban Reconstruction". She is Editor of www.sdct-journal.com (ISSN 2241-4010) and Editor of Greek Journal www.sdct-journal.gr (ISSN 2241-4002). he has organized Scientific Seminars, Scientific Conferences and Scientific Meetings on Urban Environment and Regional Development.

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Introduction

Human civilizations and societies from ancient times until today, have faced countless and diverse challenges and disasters. The continuous increase in urbanization, climate change and the complexity of the city are some of the various causes, which make the urban resilience of cities necessary to face modern challenges. This paper deals with the assessment of the current situation of the Municipality of Elliniko – Argyroupoli in the context of urban resilience.

This paper aims to analyse and explain the current situation of the Municipality of Elliniko - Argyroupoli regarding the challenges that cities are called to manage so that they can be considered urban resilience for the prevention and confrontation of various challenges.

The first part constitutes a general theoretical framework to better understand conceptual determinations. The definition of urbanization and climate change and the correlation between the two terms are mentioned. In addition, the terms disaster and risk are clarified with a view to a better understanding of natural and technological disasters. The term urban resilience, which is the most important part of the present work, the term sustainable development and the interrelated link between the two terms, are defined.

The second part is the research part of the work which concerns entirely the case study of the Municipality of Elliniko-Argyroupoli. Firstly, examples of natural disasters that have taken place in the municipality that has been studied for the last ten years are cited. In addition, the operational plans for civil protection for the Municipality of Elliniko - Argyroupoli are mentioned in the context of preventing and dealing with impending disasters and the sustainable urban mobility plan of the municipality of study is presented. Finally, the management plan for the waste of the Municipality of Elliniko – Argyroupoli is presented.

The third chapter makes a detailed assessment of the current situation of the study area. In particular, the SWOT analysis is presented to better understand the current situation of the Municipality of Elliniko - Argyroupoli. Following the collection of anonymous questionnaire replies, analysis and statistical processing are carried out with means of statistical analysis to explain the results of the questionnaire "Urban Resilience: Cities against contemporary challenges".

This research aims to draw some conclusions for the assessment of the urban resilience of the Municipality of Elliniko-Argyroupoli.

Cities and contemporary challenges

Urbanization and climate change

Urbanization is a phenomenon that has been observed since ancient times. The reasons vary, such as social, economic as well as environmental (United Nations; Environment programme). Today, half of the world's population lives in urban areas. In 1950 a third of the world's population lived in urban areas and according to the United Nations in 2050 it is estimated that 70% of the world's population will live in large urban areas. However, sustainable development depends to a considerable extent on managing urban development to achieve sustainable cities in both developed and developing countries (World Urbanization Prospects, 2018).

The quality of life in cities is inextricably linked to the rate at which cities are drawing on and managing the natural resources at their disposal. Urbanization is linked to the great pressure on the environment and land, the increased demand for basic services, infrastructure and jobs

(United Nations? Environment programme). Therefore, changes are taking place in the way of life, culture and behaviour of citizens, resulting in the formation of the demographic and social relationship of urban areas. Due to urbanisation, there is a continuous upward trend in the number of inhabitants living in urban areas in relation to rural dwellers (World Urbanization Prospects, 2018). The increased concentration of people in large cities results in increased economic activities, increased demand for infrastructure and housing. Because of the above, cities are more vulnerable to natural disasters such as the effects of climate change. The successful implementation of urban resilience contributes to the reduction of social and economic losses because it requires the adoption and implementation of immediate policies to achieve sustainability and address urbanisation to protect the environment (United Nations? Environment programme).

The definition of climate change is linked to the long term to weather phenomena on Earth, such as temperature, sea level and frost. The earth's climate has changed rapidly several times since the planet was created, 4.5 billion years ago. It has undergone extended periods of hot temperatures as well as periods of glaciers. These cycles have lasted about tens of thousands or even millions of years. Over the last 150 years, known as the "industrial age", temperatures have risen faster than in any other era (the European Union).

Abrupt climate change has obvious effects, which are distinguished from changing temperatures and rising sea levels resulting in the melting of polar glaciers as well as more frequent occurrences of rainfall and flooding. These effects can bring about fundamental changes in economic, social and environmental terms. In particular, they can be able to they alter water resources, the integrity of ecosystems, public health, industry, agricultural production as well as transport (Ministry of Environment & Energy).

The draft of the Intergovernmental Panel on Climate Change (IPCC) points out that climate change, and in particular global warming, is causing far-reaching consequences affecting the oceans, winds and rainfall in many regions of the world (International Panel on Climate Change, 201) 9). The high intensity of extreme weather events combined with the increased frequency results in overheating of the temperature of marine waters. In addition, a 2°C rise in temperature will have a particularly significant impact on both the environment and people. Efforts to eliminate the greenhouse effect by reducing carbon dioxide emissions and greenhouse gas emissions will reduce the effects of climate change (European Council of the European Union).

Global warming as well as the phenomenon of urbanisation contribute to warming in cities and their surroundings, especially during events related to elevated temperatures, such as heatwaves. Temperatures during the night are more affected by this phenomenon than the temperatures of the day (International Panel on Climate Change, 2019).

Natural and technological disasters

A disaster is defined as any rapid or slow development of a natural or technological event in marine, land and airspace which may cause far-reaching adverse effects on both man and the natural or man-made environment. For a disaster to be included in the database of the United Nations International Strategy for Disaster Reduction (EM-DAT) at least one of the following criteria must be met: 10 or more dead, 100 people reported to have been infected, call for international assistance and declaration of a state of emergency (EM-DAT, The International Disaster Database for Research on the Epidemiology of Disasters - CRED).

Often in the literature, the terms destruction and danger are mistakenly confused and therefore it is necessary to differentiate the two terms (Abhaya S. Prasad & Francescutti, 2017). The United Nations International Strategy for Disaster Reduction (2004) defines as a risk any natural events or human behaviour that can have consequences for man, social disturbance, destruction of property or deterioration of the environment. However, a disaster is the possible consequence of a risk in which a community or a population cannot handle the effects of the risk, given the resources at its disposal. Therefore, a risk can be an event that will take place independently of human intervention, but the impact of a feed could be reduced or even avoided (Abhaya S. Prasad & Francescutti, 2017).

Risks can be grouped into three categories: technological, physical and environmental. Technological risks are characterised as industrial, nuclear and even pollution, while environmental risks relate to the degradation of the environment permeating the ecosystem, the environment, or natural resources, such as climate change. Natural hazards are events that are the direct result of natural processes, while technological and environmental hazards have come because of human behaviour (Lekkas, 2000).

The natural disaster is a serious, large-scale, adverse event that originated because of natural processes of the biosphere and the earth (Sapountzaki & Dandoulaki, 2016). A natural disaster can be a rapid, large or momentary collision between the natural environment and the social environment. economic system (Lekkas, 2000). This results in loss of property and life, problems in human health as well as injuries, damage to the natural and man-made environment. At the same time, it can cause extensive economic and social losses, the size and severity of which depend on adaptability, vulnerability, and the ability to recover (Bankoff et al., 2004).

A technological disaster is defined as a major accident that occurs in a high-risk installation. It is defined by the International Labour Organisation as "an incident such as a large emission, fire or explosion resulting from uncontrolled developments during an industrial activity, leading to serious a danger to man, immediate or delayed, inside or outside the installation, and the environment, involving one or more dangerous substances' (International Labor Organization, 1988).

Urban resilience and sustainable development

Urban resilience is defined as the carrying capacity of cities to operate in such a way that people living and working in cities, especially the vulnerable and the poor, survive and thrive regardless of the unexpected crises or even disasters they face (Index, City Resilience, 2014).

With the continuing increasing trend of urbanisation, cities are faced with a variety of acute shocks resulting both from long-term pressures, such as the effects of climate change, and from natural and technological disasters. As a result, they can cause incalculable effects on people's health and safety, the economy, and the natural environment. As a result, they can have incalculable effects on people's health and safety, the economy, and the natural environment. As a result, they can have incalculable effects on people's health and safety, the economy, and the natural environment. As a result, urban resilience becomes necessary, without however being limited only to the traditional approach to the prevention and management of risks, but also focusing on the creation of preventive and adaptive policies to deal with any unexpected threat (Labaka et al., 2019).

The scale of urban risk is increasing, while at the same time it is becoming more unpredictable due to the complexity of the city as well as the uncertainty associated with various risks. Urban resilience helps to bridge the gap between disaster risk reduction, resilience to climate change, and ensuring the well-being of society. One of the main objectives of urban resilience is to improve the performance of a system for prevention and to address multiple risks (Index, City Resilience, 2014).

The concept of sustainable development is defined as the form of development policy that aims to meet the economic, social and environmental needs of society to ensure both short-term and long-term prosperity (European Commission). Sustainable development must be based on and respond to existing needs while at the same time ensuring the well-being of future generations. The aim is not to degrade or alter the environment while contributing to long-term economic growth (European Commission). On the other hand, the environment has been sacrificed and a large number of natural resources have gradually been exhausted, making sustainable development a major issue. It is therefore necessary to achieve it, cooperation between the government of each country, its local government and non-governmental organizations (Council for Sustainable Development).

The immediate aim of the Council of the Federation of Enterprises and Industries (SEV) for sustainable development is that by 2050, 9 billion people will live in satisfactory living conditions on the planet (Council for Sustainable Development). Today, humanity consumes more than the earth can produce, so it is no longer possible to focus only on economic growth and development. The burden on the environment, climate change, the increasing trend of urbanisation, food shortages and social inequalities are some of the factors that threaten humanity. However, businesses committed to sustainable development are a key factor in the delineation of change, pointing to sustainability to other social partners such as governments and local authorities. The axes of extroversion, competitiveness and innovation create jobs as well as a cohesive society by developing a productive economy with respect for the environment (Council for Sustainable Development).

Analysis of the existing situation of the Municipality of Elliniko - Argyroupolis

The union of the Municipality of Hellinikon (Municipal Community of Hellinikon) and the Municipality of Argyroupoli (Municipal Community of Argyroupoli), which resulted from the Kallikratis Programme in 2010, created the Municipality of Elliniko - Argyroupoli (Law 3852/2010 Government Gazette A 87/7-6-2010). The Municipality of Elliniko - Argyroupoli belongs to the Regional Unit of the Southern Sector of Athens, consisting of 51,356 permanent residents, according to the census of the Hellenic Statistical Authority (ELSTAT). that took place in 2011 and occupies an area equal to 15.4 sq.km. (Municipality of Elliniko Argyroupolis). The altitude of the municipality corresponds to 56 meters and the climate is Mediterranean, according to the Köppen scale classification: Csa (DB. City. com). It is located by the sea while at the same time a part of it is located at the foot of mount Hymettus.

Examples of natural disasters in the Municipality of Elliniko - Argyroupoli

Various natural disasters have affected, on a small scale, the Municipality of Elliniko - Argyroupoli in the last ten years, but no disaster related to a technological accident has been recorded. Several fires have taken place in the Municipality of Elliniko - Argyroupoli but they were small scale and were extinguished immediately without causing adverse effects on the property or the environment and without human casualties. In May 2021, a small fire was recorded in a forest area of Argyroupoli but thanks to the rapid response of the fire brigade, it did not take a large area. Moreover, according to the official website of the municipality another fire had broken out but was quickly noticed by the voluntary forest protection body of the municipality. It is necessary to mention that there have been attempts at arson in forest areas near the Municipality of Elliniko - Argyroupoli and several fires that broke out were investigated and attributed to inflammatory actions (Municipality of Elliniko Argyroupoli).

In addition, the geographical position of Greece, which is located above the tectonic plates, favors earthquakes. Specifically, in the Municipality of Elliniko - Argyroupoli took place an earthquake of 2.6 on the Richter scale in 2020 and another earthquake of 5.1 on the Richter scale in 2019. The consequences of the two earthquakes were not serious and did not cause large-scale disasters. Thanks to the information and awareness of the citizens through the official website of the municipality as well as the social media, there were no victims (Municipality of Elliniko Argyroupoli).

Also, due to climate change, extreme phenomena have been observed, such as severe weather, heat waves, heavy rainfall, and snowfall. The consequences of climate change may affect and cause adverse effects even at a local level, due to the coastal area of the Municipality of Elliniko - Argyroupoli. A possible impact of climate change is the rise of sea levels, which can affect all residents and employees of the municipality and the sector that will be affected at an average level is the building stock and materials (Giaourdimou, 2020).

Although the municipality of Elliniko - Argyroupoli is included with a percentage of 100% within a water district in the catchment area of the Attica basin, a flood event has historically been recorded but it was not significant and therefore, it has been characterized as a low-risk flood zone according to the "Kallikratis" program. A river basin means "the land area from which all rainfall and/or snowfall of a river is drained of all the rainfall and/or snowfall of an area through the hydrographic network (successive streams, streams, rivers, and possibly lakes) and is drained into the sea through the delta of a river" (Flood Risk Management Plan of the River Basins of the Attica Water District, 2017).

Finally, the COVID-19 pandemic is a natural disaster that has been taking place on a global level since the end of 2019 and has naturally affected at a local level the Municipality of Elliniko - Argyroupoli in various aspects of people's daily lives and in areas such as public health, building stock and tourism with a high level of risk, while sectors such as transport and energy are affected at lower levels of risk. However, due to the complexity of the city, all sectors are interrelated as the increase or decrease of one sector can negatively affect another sector resulting in adverse effects both on a social, economic, and even environmental level (Yaourdimou, 2020).

Civil protection operational plan

One of the main priorities and obligations of each municipality is the protection of human life, property and the health of the citizens in the context of its social mission (Law 3013/02, Government Gazette 102/Α΄/1-5-2002). The purpose of any operational plan for Civil Protection is to prevent and deal with possible natural or technological disasters through the formation of a system of effective mobilization and preparation of competent services. the Municipality of Elliniko - Argyroupoli and the stakeholders (Politis, 2018).

For the Civil Protection Plans of the Municipality of Elliniko-Argyroupoli to be effective, it is necessary to prepare for emergency response, detailed planning, effective organization and staffing, adequacy of material resources as well as integrated coordination of these

(Emergency Action Plan, 2018). Finally, it is necessary to meet the requirements of effective and timely management of various risks, which should be based on prevention, preparedness, response and finally recovery. One of the most basic planning principles in response to and management of mass emergencies is coordination and excellent cooperation between the competent bodies, with clear and specific roles, before, during and after the outbreak of a disaster (Emergency action plan, 2018).

The Municipality of Elliniko – Argyroupoli on its official website has published an updated plan of actions for the organized evacuation of citizens for reasons of protection from impending destruction due to forest fires in August 2020, which was undertaken by the Directorate of Environment and Civil Protection (Plan for dealing with emergencies due to forest fires). In addition, it has published another Operational Policy Plan Protection for the confrontation of natural disasters, which contains all the necessary information for the immediate response to forest fires, emergencies, earthquake and flood cases (Emergency Action Plan, 2018). In addition, in the context of the implementation of a system of effective information and prevention of the Directorate of Environment and Civil Protection has published a protection guide under the name "Elli and Argyris learn about the fire, the earthquake, the flood" which addresses in the form of comics a strong message to the students at the school community (Directorate of Environment and Civil Protection).

In addition, the Municipality of Elliniko - Argyroupoli has made sure to publish on its official page on social media, useful instructions as well as information on the self-protection of citizens in cases such as severe weather conditions, heatwaves, fires as well as earthquakes. daily based on the internet, thus making it more immediate and timelier to inform citizens as well as to raise their awareness.

Finally, a major earthquake response exercise was carried out under the name "SEIZHON 2019", which included four seminars aiming at the readiness for rescue, the effectiveness of the stakeholders involved as well as the optimization of their cooperation (Fire Brigade of Greece, 2019).

It is necessary to mention at this point that the Municipality of Elliniko - Argyroupoli is a model of the municipality. This is reflected by the fact that it was awarded in 2019 in the framework of the annual bravo sustain and ability, dialogue and awards for its multidimensional effort in the organization and execution of Civil Protection plans and prevention measures for the Protection of the Natural Environment (Quality Net Foundation, 2019).

Sustainable urban mobility plan

A Sustainable Urban Mobility Plan is defined as the Strategic Mobility Plan which aims to meet the needs for people's mobility by reducing the use of private cars and increasing travel through more sustainable modes of transport. In addition, it aims to ensure a better quality of life through the transport of goods to the urban and peri-urban fabric. It builds on existing planning practices and includes all areas indirectly or directly involved in the scope of employment of a sustainable urban mobility plan (Sustainable Urban Mobility Plan). Sustainable urban mobility plans contribute to the sustainable development of urban areas through the design of policies and actions to reduce air pollution, energy consumption, traffic congestion, etc. (Municipality of Elliniko Argyroupoli).

The Municipality of Elliniko - Argyroupoli, through the Integrated Sustainable Urban Mobility Plan (SUMP), aims to ensure accessibility of services and jobs to all citizens, to improve both the protection and safety of commuters. In addition, it contributes to the mitigation of air pollution and noise, while increasing economic efficiency and result. the quality of the transport of people and goods. In addition, it contributes to the improvement of the quality and attractiveness of the urban environment (Sustainable Urban Mobility Plan of the Municipality of Elliniko Argyroupoli). The SUMP of the Municipality of Elliniko - Argyroupoli has as its primary objective the creation of a network of mild mobility roads that will operate within the municipality but also in neighbouring municipalities to improve the movement of residents. In particular, the aim is to reduce the problems found in the traffic network. More specifically, it aims to increase mild forms of transport, such as the promotion of walking and public transport, to reduce the use of private cars and the parking problems they entail. In addition, as part of the implementation of the SUMP, a bicycle path has been built in Argyroupoli to operate a single network of cycle paths in both municipal units (Municipality of Elliniko-Argyroupoli, 2018).

The sustainable development of cities develops and raises the standard of living of the region. The successful implementation of a SUMP is based on the bodies and their responsibilities to be clear for the implementation of an action. The sustainable urban mobility plan of the Municipality of Elliniko - Argyroupoli operates with a specific timetable for the implementation of works. It is necessary recently to estimate the cost in full cooperation with the technical service of the Municipality of Elliniko - Argyroupoli. Cooperation and finding available resources are reflected in the instructions of the Urban Mobility Observatory (ELTIS, 2014) in the final straight of implementing measures as to the cost of the programme. The cost of implementing the SUMP is not the responsibility of the Municipality of Elliniko - Argyroupoli alone. Each metro has an indicative cost. The presentation of the project is made per thematic category and by time priority. The cost and sources of funding and the bodies that will undertake its implementation will be assessed (Sustainable Urban Mobility Plan of the Municipality of Elliniko Argyroupoli).

Waste management plan

One of the most important and primary responsibilities and obligations of each municipality is the cleanliness and management of waste under article 75, par. 1 of Law 2463/2006 (Government Gazette 114 issue A/8.6.2006). According to the City Regulation of the Municipality of Elliniko-Argyroupoli, which is carried out for the first time in the municipality, defines as waste - waste management "the collection, the transport, transhipment, temporary storage, recovery and management of waste, including the supervision of these operations, as well as the subsequent care of disposal sites" (City Regulation, 2015).

The vision of the Municipality of Elliniko - Argyroupoli seeks an environmentally optimal and sustainable management of its waste, which can constitute a local community of "zero waste" in cooperation with other geographically close municipalities. The basic principles of the Municipality of Elliniko - Argyroupoli regarding waste management at a local level are initially the prevention of waste creation, the setting of specific quantitative targets based on both national and European policy to reduce the final disposal of waste through re-use. It also seeks to recover materials and safely recover energy from waste, which cannot be recycled. Finally, emphasis is placed on informing and raising awareness among citizens as well as the environmental education of pupils in schools (Decentralized Local Plan Waste Management of the Municipality of Elliniko-Argyroupoli, 2015).

The Local Plan of Decentralized Waste Management (TSDA) of the Municipality of Elliniko - Argyroupoli, was established by Harokopio University in the context of the implementation of a new decentralized waste management system in Attica. Its primary objective is to constitute a Local Action Plan (CSSR) with best practices for the better management of most waste at a local level of the Municipality of Hellinikon - Argyroupoli, with goals and actions for the next 10 years (2015-2025). This Local Action Plan was based on a new management model that focuses on combined actions of the Municipality as well as the Region. The aim is to analyse and evaluate the defined waste management framework of the Municipality of Hellinikon – Argyroupoli to submit proposals for practices and actions to optimize savings, natural and human resources. Therefore, this Local Action Plan includes the modern requirements and objectives of national and Community legislation on solid waste management. In addition, it incorporates the objectives of the new National Waste Management Plan for the prevention of waste as well as identifies specific qualitative and quantitative targets adopted by the Municipality of Elliniko-Argyroupoli. It highlights the necessary local projects as well as actions in cooperation with the competent bodies to achieve both the prevention and re-use and the recycling of waste to recover resources as well as reduce the waste that is buried. Finally, it places particular emphasis on the importance of raising awareness and informing citizens about the successful completion of the proposed actions and calculates the required budget regarding the investment cost for the implementation of the proposed projects and actions (Local Plan of Decentralized Waste Management of the Municipality of Elliniko-Argyroupoli, 2015).

In conclusion, it is worth mentioning that the Municipality of Elliniko – Argyroupoli on its official website has posted in Public Consultation the proposal to update the Local Waste Management Plan to collect proposals and observations from the citizens of the municipality and had held an educational event to the public in December 2021 to inform citizens about the management of bio-waste in the Municipality of Hellinikon – Argyroupoli (Municipality of Elliniko Argyroupoli).

SWOT analysis of the existing situations of the Municipality of Elliniko - Argyroupoli

Table 1 is the SWOT analysis for the Municipality of Elliniko-Argyroupoli to better understand the strengths, weaknesses, opportunities and threats of the current situation regarding the urban resilience of the municipality of Elliniko - Argyroupoli.

As can be distinguished from the SWOT analysis of the current situation of the Municipality of Elliniko - Argyroupoli, the advantages outweigh the disadvantages. Moreover, there is a possibility of preventing and addressing the disadvantages through the opportunities presented in the table as well as the reduction of the impact of the potential threats threatening the Municipality of Elliniko-Argyroupoli.

On-the-spot investigation

For the preparation of this paper, the bibliography was collected through bibliographic research and review, which is available in books and scientific references. This bibliographic research was conducted in conjunction with the search for scientific articles and studies through the Internet which have been published in a journal as well as official websites. More specifically, the official website of the Municipality of Elliniko - Argyroupoli was used.

Firstly, this research was conducted during the winter academic semester of the year 2021-2022. The present survey was self-funded from Roido Mitoula, Professor of the Department of Economics and Sustainable Development of Harokopio University. More specifically, the creation of the questionnaire, the instructions and delivery of the survey were undertaken by Roido Mitoula. Furthermore, this research constitutes quantitative research and statistical means of descriptive statistics were used for the collection, processing and presentation of the results. More specifically, this present research was a primary form of research as well as inductive. For the collection of the sample probability sampling was used through questionnaires for the collection of primary data filled in electronically or in person, mainly, by citizens of the Municipality of Elliniko - Argyroupoli. In particular, they were supplemented through the "Google Forms" program. ", 67 specially designed questionnaires with 30 closed-ended questions about the place of residence of the respondents. The completion of the questionnaires took place from October to January of the year 2021 – 2022.

Table 1: SWOT analysis of the Municipality of Elliniko – Argyroupoli.

	Strengths	WEAKNESSES
INTERNAL ENVIRONMENT	▪ Prevention of raising awareness and informing citizens about impending disasters ▪ Detailed and careful design of civil protection plans ▪ Preventive actions and exercises in cases of emergency ▪ Satisfactory and effective cooperation with competent bodies ▪ It provides the opportunity to citizens to address ideas and suggestions regarding the improvement of their everyday life	▪ Large-scale municipality ▪ Difficulty in moving due to the urban area ▪ Inadequate traffic lanes ▪ Air pollution due to the increased use of private cars ▪ Increasing trend of urbanization
	OPPORTUNITIES	**THREATS**
EXTERNAL ENVIRONMENT	▪ Possibility of a grant through programs to optimize the sustainability of the Municipality of Elliniko-Argyroupoli ▪ Ability to cooperate with neighboring and other municipalities ▪ It can be a model of a municipality for other municipalities as an example to be emulated	▪ Complexity of the city ▪ Increasing trend of urbanization ▪ Scalar Change ▪ The municipality, due to its geographical position, is more vulnerable to forest fires and hydrological disasters (tsunami, rise of the sea)

For the execution phase of this present survey the participation was voluntary as well as confidential. Regarding the feasible and the ethical factor, was civil and ethical and the were no questions where the responders must answer even, they don't know the answer. Also, in the questionnaires they were not personal questions reflecting the researcher's bias (Glasow, 2005)

Finally, the questions were not long or involved double negatives according to McIntryre 199. Also, all the questions were consisted of closed-ended questions because according to Salant and Dillman 1994 those questions does not require much effort from the responders.

According to the census of the Hellenic Statistical Authority that took place in 2022 the permanent population consists of 53,1% women and 46,9% men which is accord to the sample of this present research. (Hellenic Statistical Authority, 2022). Regarding the age group in the

Municipality of Elliniko-Argiroupoli the age group is 15-39 years old combining the two municipalities' units according to the Hellenic Statistical Authority that have been conducted in 2001. (Hellenic Statistical Authority, 2001) while in this present paper over 50% of the respondents was between 18 and 34 years old which is accord to Hellenic Statistical Authority.

Also, regarding the marital status of the population of the Municipality of Elliniko-Argiroupoli 52% of the population were single and 48% were married which agrees with the demographic findings of the present survey (Hellenic Statistical Authority, 2011).

At this point, limitations of this present study must be acknowledged. A possible methodological limitation found to be the sample size. Even though some of the demographic is accord to the census of the National Statistical Authority the sample is considered to be small. Another limitation of this present research is the "sample bias" that means, even though measures was taken to prevent this the respondents may not truly be a random sample. In addition, lack of available data was observed about the demographic and social statistics for the municipality of Elliniko-Arguroupoli.

Finally, this research can be used for further research for the assessment of urban resilience research not only in the study area but in national level. In addition, can be used as a starting point for the collection of views of the residents of the study area or any other municipality for future research and studies aimed at improving the standard of living as well as their quality of life.

Results

Regarding the gender factor, 52.2% of respondents are women while 47.7% are men (Figure 1). On the age of the respondents, 30% of respondents are 18 to 24 years old and 26.9% of respondents are 25 to 34 years old (Figure 2). 25% of the sample is a graduate of an I.E.K. and 24% of the sample is a high school graduate (Figure 3). As far as the marital status of the respondents is concerned, 57% of them are unmarried (Figure 4) and 37.3% of the sample live with parents or a partner or a friend (Figure 5). 33% of respondents are full-time employees (Figure 6) of which 51% are self-employed (Figure 7) and 51% could and would like to work remotely during the covid-19 pandemic (Figure 8). Most of the sample by a wide margin (52%) stated that it has an annual net personal income of up to 6,000 euros (Figure 9). 93% of the sample lives in the Regional Unit of the Southern Sector of Athens and specifically in the municipality of Elliniko – Argyroupoli (62 out of 67 total responses) (Figure 10). The survey showed that most respondents live in a municipality located by the seaside (48 responses) (Figure 11). 27% of the respondents consider the change of the local climate seasons as the most important, direct or indirect, consequence of climate change that has affected their municipality/city (Figure 12).

The majority of respondents consider that fire, explosion and/or dispersion of toxic fumes and gases are unlikely to occur in their municipality/city (37 responses) (Figure 13). 32.8% of respondents say they are little informed about climate change (Figure 14).

Newspapers/magazines as well as the organisation where respondents work are how respondents say they are not informed about climate change at all (Figure 15). 41.8% think that climate change is too serious a problem for the planet (Figure 16). Most respondents consider that the agricultural sector may be more affected by climate change in our country by a large margin than the rest of the sectors (Figure 17). Respondents do not consider climate change to be an important reason to support an MP (23 responses) and a political party (21 responses), for a MEP they consider it quite an important reason (23 responses while for a mayor and regional governor they consider climate change as a very (24 responses) and especially important reason respectively (24 replies) (Figure 18). Most respondents replied that the main means of transport before the pandemic was Public Transport (26 responses) as during the evolution of the COVID-19 pandemic the main means of transport was the car (37 responses) (Figure 19). Most respondents chose the option "overcrowding on public transport" as the main reason for choosing a means of transport. (46 responses) (Figure 20). 51of respondents said they would focus on zoning sidewalks, cycle paths as well as upgrading infrastructure. (Figure 21). Before the COVID-19 pandemic, most respondents said that they visit the open public space of their neighbourhood quite a bit (29 responses), while during the evolution of the COVID-19 pandemic a little bit (19 responses) (Figure 22).

The majority of respondents chose contact with nature (38 responses), mental health (38 responses) and socialization for the justification. (37 replies) (Figure 23). The majority of respondents said they would focus on cleanliness (51 responses) and the modernization of urban furniture (48 responses) if they had the opportunity. (Figure 24).

35.8% of the respondents consider the image that the Municipality presents to its residents, employees and/or visitors to be positive about the emergency response? (Figure 25). Many respondents consider that it is quite necessary for their municipality/city to adapt to the emergency response before the COVID-19 pandemic (33 responses) while during the evolution of the COVID-19 pandemic they consider that it is very necessary (25 responses) (Figure 26). Most respondents consider that priority should be given to the loss of life consequences of emergencies (55 responses) (Figure 27). 35.8% of respondents consider that the first person responsible is the Municipality for the adaptation (taking of measures/ interventions) of your city/municipality regarding the emergency response (Figure 28).

Most respondents consider that emphasis should be placed on early warning systems for emergencies (49 responses) as well as on information campaigns on emergency response (47 responses) (Figure 29). Most respondents feel that they are not at all aware of how to react if a major technological accident. (26 replies) (Figure 30). Many respondents would like to receive instructions via text messages on mobile (SMS) and audio notifications. (45 replies) (Figure 31). 34.3% of respondents say they are very satisfied with the operation of the 112-emergency number (Figure 32). 49.3% of respondents say that they have never been asked for their opinion or to take part in the planning of measures/interventions regarding the adaptation of your municipality/ city to the emergency response? (Figure 33). 44 of respondents say that filling out questionnaires is the way they could or would like to participate (Figure 34).

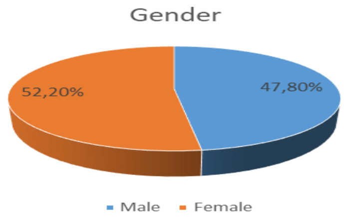


Figure 1

Figure 2

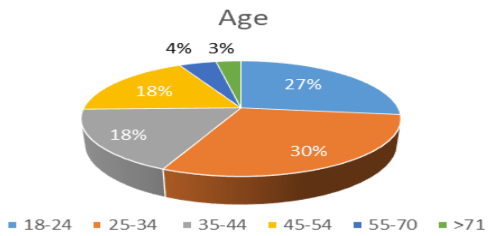


Figure 3

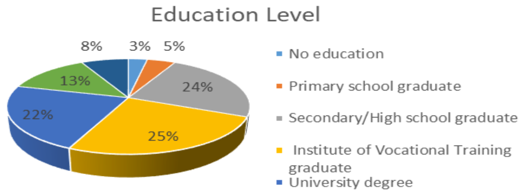
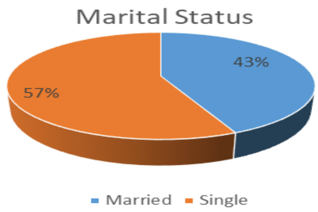


Figure 4



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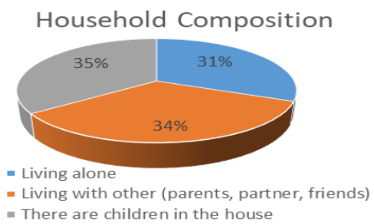

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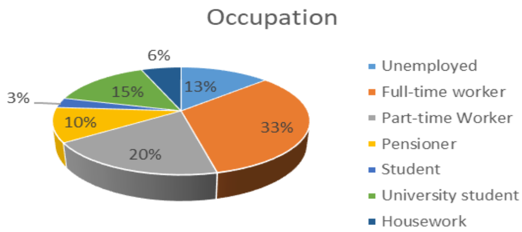

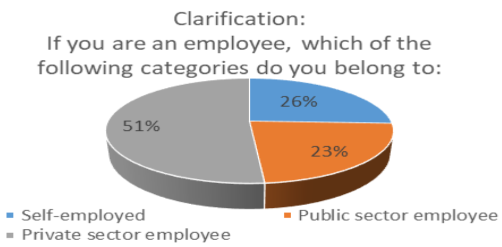

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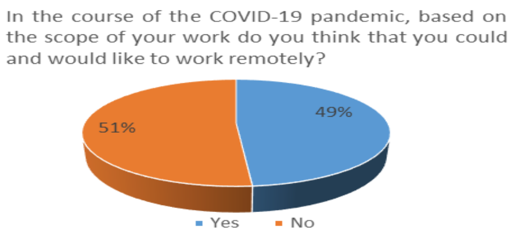

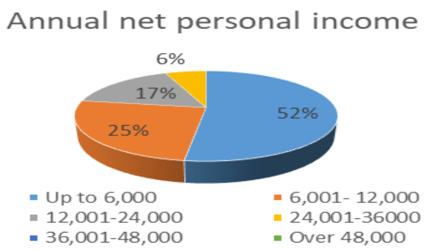

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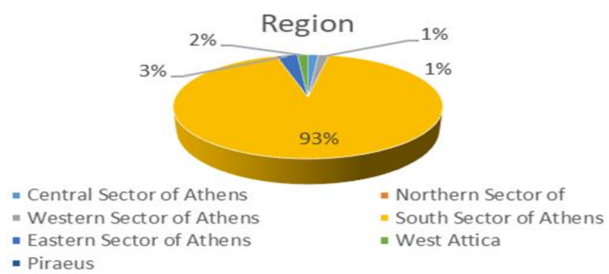

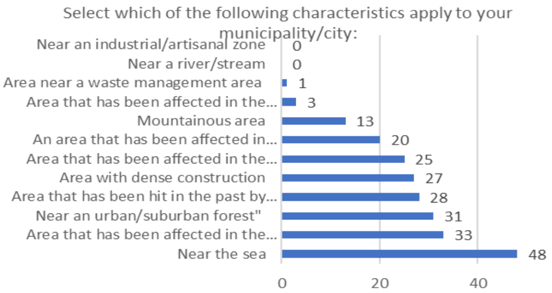

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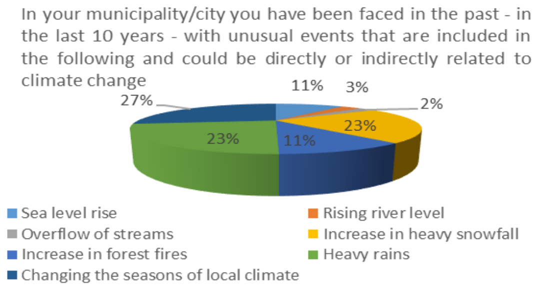

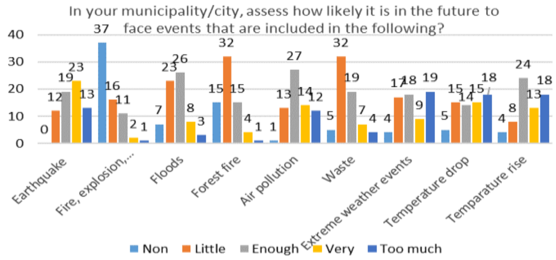

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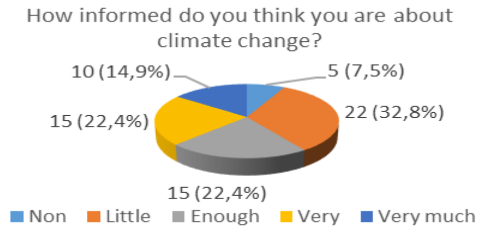

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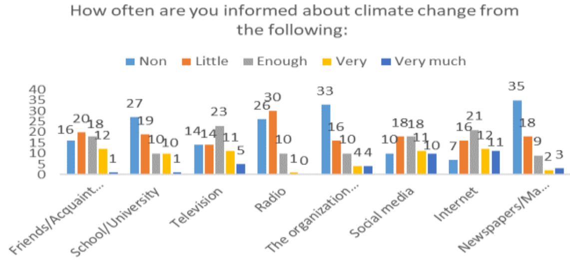

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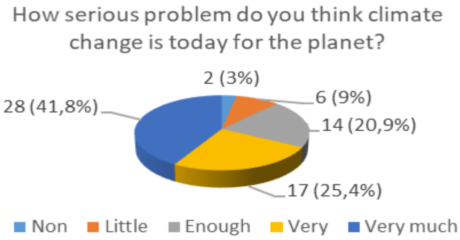

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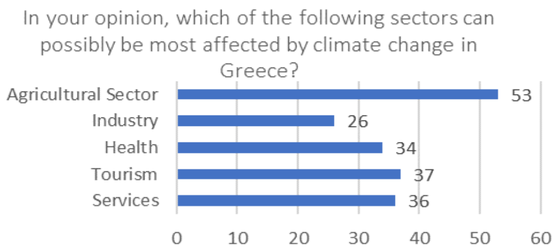

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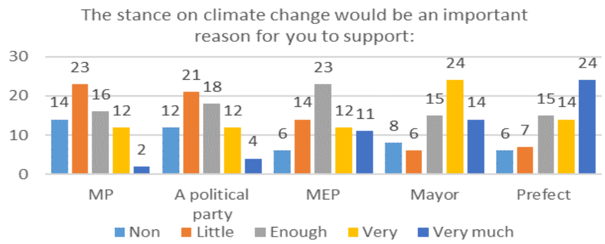

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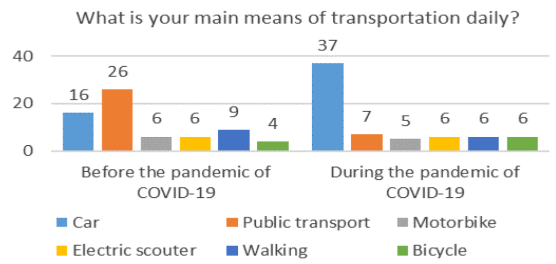

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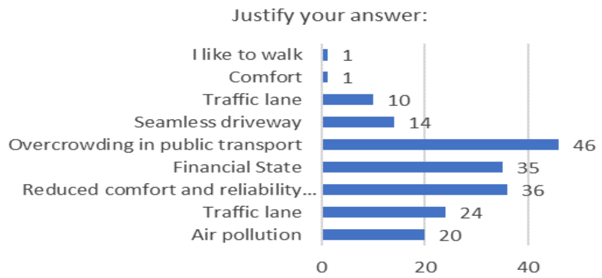

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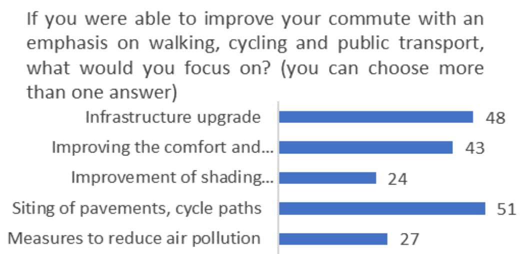

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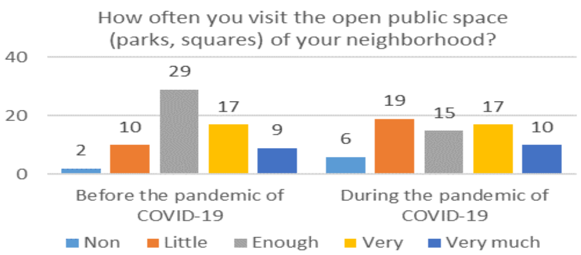

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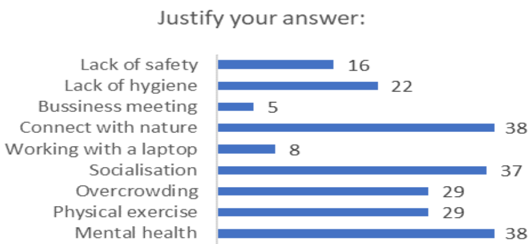

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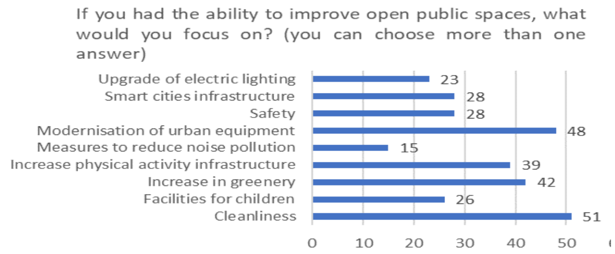

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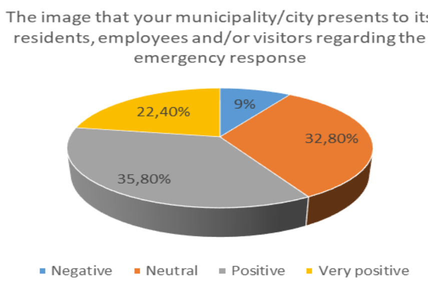

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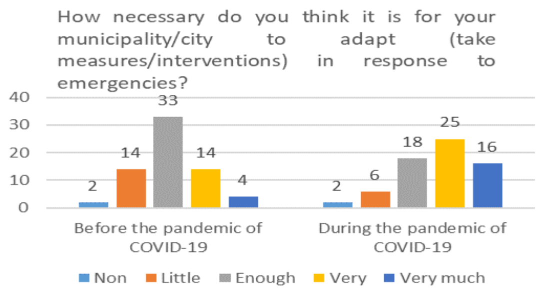

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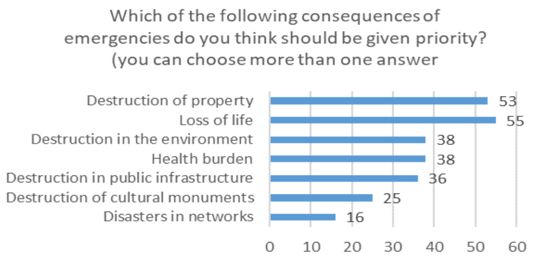

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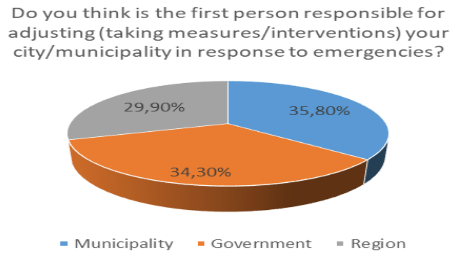

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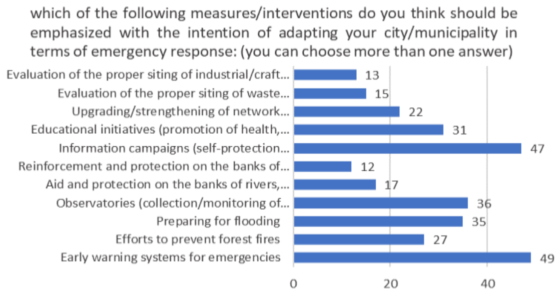

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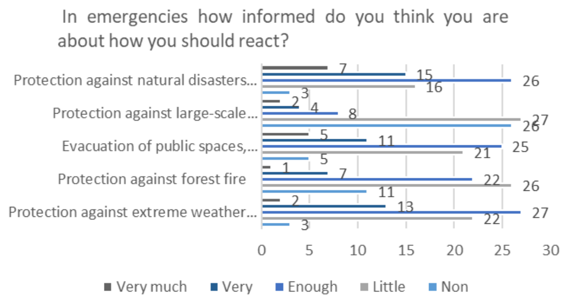

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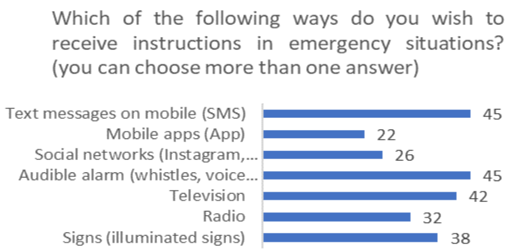

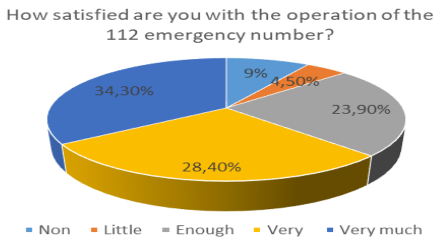

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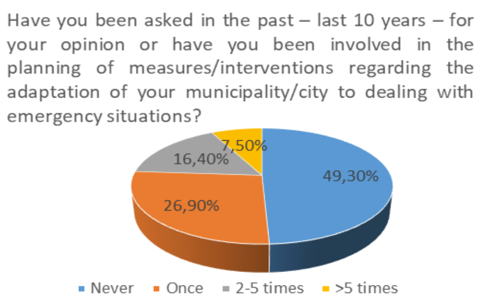

Figure 34

Conclusions

According to the results of the conduct of the survey, several conclusions can be distinguished. Initially, although most respondents do not consider that they are fully informed about climate change, (specifically 32.8% of respondents replied that they are not informed), the majority overwhelmingly consider climate change as a major problem nowadays (specifically 41.8% of respondents consider it to be too serious a problem). Respondents say that climate change would be too important a reason to support a regional governor (24 responses) while for a mayor most respondents say it would be a particularly important reason (24 responses).

The COVID-19 pandemic has affected respondents in various aspects of their daily lives. Initially, as can be seen in Figure 11, the evolution of the COVID-19 pandemic has greatly affected respondents as to their main means of transport. Whereas before the COVID-19 pandemic, 16 respondents used the car as a basic means of transport, as the course of the pandemic, the car was selected by 37 respondents. Similarly, public transport was chosen by 26 respondents as the main means of transport before the coronavirus pandemic, while during the pandemic, only 7 respondents used public transport as the main means of transport. According to the justification, the prevailing reason for the choice of the main means of transport is overcrowding in public transport, followed by the reduced comfort and reliability of public transport. In addition, respondents during the COVID-19 pandemic visited less the open space of their neighbourhood than before the pandemic, and the prevailing justifications for the answers are contact with nature and mental health (Figure 15). Moreover, during the evolution of the coronavirus pandemic, a rapid increase in the necessity of adapting-taking measures/interventions related to emergency response is being observed (Figure 18).

The largest percentage of respondents consider positive the image that their demos / city projects to its residents, employees and / or visitors regarding the emergency response (35.8% of respondents chose "Positive" and 22.4% chose "Very positive"). The answers regarding the person responsible for taking measures/ interventions were divided, as can be seen in Figure 20. In general, the majority of respondents say they are satisfied with the operation of the emergency number.

It is necessary for the Municipality of Elliniko - Argyroupoli to place further emphasis on the response of citizens to emergencies, as shown by Figure 22. In addition, it should focus on citizen participation because, as can be seen in Figure 25, most of the citizens have not been asked to contribute in any way to the response to emergencies.

According to the analysis of the current situation and the conduct of a primary form of research, as analysed in the above chapters, it is concluded that the Municipality of Elliniko - Argyroupoli can become a model municipality in the analysis and preparation of emergency plans, sustainable urban mobility plans as well as plans for the waste management. In conclusion, the Municipality of Elliniko - Argyroupoli has the potential to achieve to the maximum extent possible the urban resilience to be able to face various challenges through analytical planning, taking policies and interventions, taking policies at a preventive level, further sensitizing, and informing citizens as well as their participation.

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Smart Contract in Food Supply-Chain

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Abstract

Blockchain can assist food supply chain in many ways. Notably food traceability and trading of food through pre-existing contracts can make the supply-chain much faster. In an environment of global food transport though the uncertain corridors (passing through channels having unknown bacteria and viruses alongside delays in transportation), pace is the key. Transparency and accountability as well remain the other two most important pillars. Therefore, blockchain remains the singular most important factor ensuring timely delivery with optimum use of resources. Functioning of a blockchain depends by and large on its automated market maker (AMM) platform to pave the way for a smooth, timely and frictionless movement of goods. Essentially each AMM typically functions through a pre-determined set of sequential algorithms called as 'Smart Contract (SM)'. Therefore, 'those SM holds the key in true sense. Correct algorithm, keeping in mind specific geographic, demographic and other necessary parameters would let the AMM supply ample liquidity of pre-determined orders. This is fast, accurate and smooth in operation, provided the code underneath is written properly. This in effect reduces food wastage, contamination, excess or no delivery in time and perhaps most importantly increases the traceability. This extended abstract discusses all possible and plausible facets of 'Smart Contract' utilisation in food supply-chain.

Keywords

Traceability, smart contract, automated market maker

Presenter Profiles

Bikramaditya Ghosh is an Erasmus+ Professor of Finance and Analytics. He has a proven track record in publication with several noted articles to his credit. His research areas are Agri-Finance, Green Finance, Behavioural Finance & Financial Econometrics. He is also a Post-Doctoral Researcher at Harper Adams University in the UK.

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Extended Abstract

Globalisation and intense market competition made food supply chain industry quite a complex one. Food sourcing at the raw level to the processed level, self-life study, supply chain inefficiency, other unforeseen challenges make this issue a rather difficult one to deal with. Blockchain on the other hand, creates detailed pool of contacts through digital ledgers and creates a pool of liquid ready-made contracts between various levels of participants involved in this chain. Farms to processors and finally the retailers all can benefit from this seamlessly. In fact, it would assist in reducing low quality food and frauds as well. If we look through a common consumer's lens, we find true and reliable information about the quality and source of the produce, shelf life, dietary details alongside the entire transaction path. Recent literatures suggest that consumer concern about these issues are clearly can be taken care by the implementation of blockchain (Ge, L., et. al., 2017). Further, such provides the possibility for consumers to interact directly with producers. Thus, they can understand the entire process in detail. Regulatory perspectives are benefitted too, as blockchain makes reliable and accurate information available (Zhou, Q., et. al., 2016). Moreover, the inherent property of immutability makes blockchain even more trustworthy. As an example, the DNA of livestock animals or pesticide residues of grain cannot be altered. Checking such data by the regulators become easy as all the samples will be visible in a distributed ledger technology system (DLT). Furthermore, these checks are both cost-efficient and quick. This kind of transparency could surely assist in detecting horse meat scandal (2013) [1]type of events (Kamath, 2018; Montecchi, M., et. al., 2019).

Of late, many solutions facilitated by blockchain have been proposed to upgrade and refine the traceability of agricultural produce. Radio Frequency Identification (RFID), a non-contact automatic identification have been proposed by Tian F (Tian, 2016). RFID can trace products very effectively. Another innovative blockchain-based traceability system linked with IOT have been proposed by Caro in 2018 (Caro, M. P., et.al., 2018). This is not only confined in academia. Many corporations have already implemented such practices to good effect. Alibaba, Wal-Mart and JD.com are implementing food traceability projects and using blockchain technology. They are tracking the entire process of production, processing and sales. In October 2016, retail giant[2] Wal-Mart, Tsinghua University and IBM applied the Hyperledger blockchain system to food supply chain management. This in process explored the entire Chinese pork supply chain along with United States mango supply chain as a pilot. It was successful. In March 2017,[3] Alibaba and Australia Post explored the 'paddock to plate' to good effect. This provided useful breakthrough regarding the identification of counterfeit food.

During 2017, the world's top ten largest food giants,[4] including Wal-Mart, Nestle, Dole, and Golden Food, reached a partnership with IBM for integrating the blockchain into its supply chain. They wanted the entire network (namely farmers, brokers, distributors, processors, retailers, regulators, and consumers) to be scanned regularly through a continuous blockchain intervention in order to identify causes behind foodborne illnesses at the earliest. Foodborne diseases often create nuisance to public health, especially in developing nations.

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[1] https://www.theguardian.com/uk/2013/feb/15/horsemeat-scandal-the-essential-guide

[2]https://one.walmart.com/content/globaltechindia/en_in/Tech-insights/blog/Blockchain-in-the-food-supply-chain.html

[3]https://www.ipc.be/news-portal/e-commerce/2017/03/30/13/20/australia-post-joins-alibaba-to-trace-food-exports

[4] https://fortune.com/2017/08/22/walmart-blockchain-ibm-food-nestle-unilever-tyson-dole/

Contamination, exposure to heat and extending shelf life of perishables without any valid reason makes the situation even more difficult. Blockchain structure (with an open ledger of accounts and transactions) ensures each constituent of this chain share their data completely and safely. This unique technology can track the origin of food and therefore helps to build trust between producers and consumers. This in turn would create an accountable and traceable system. Once reported the data cannot be altered in a blockchain, ensuring no wrong reporting. Farm to table can be completely monitored and seamlessly checked in real-time. Many important contributors in this space are ChainTrade, Farm2Kitchen, Arc-net, Owlchain, TE-Food & IBM Food Trust. In an attempt to make the system better ChainTrade is constructing a decentralised trading platform for tokenised commodities and Arc-net is making a system for brand protection alongside validation.

We find 'Smart Contracts' at the helm of affairs as we delve deep into this blockchain ecosystem. Smart contracts are typically algorithms, that run the automated market maker and in turn operate the entire blockchain from behind. It creates a pool of liquidity of possible contracts between prospective buyers and sellers. Typically, the efficiency of a blockchain revolves around the pool of liquidity. Unlike a traditional exchange, they create a pool of liquidity through peer to contract trade instead of existing peer to peer trade. Liquidity made the trading easier, faster and cheaper at the same time. Pools of liquidity typically consist of tokens, whose price can be modified by changing the mathematical equation behind it. This feature helps in optimization. Therefore, it allows timely payments between stakeholders as well. In addition to that AMM provided incentives to the liquidity suppliers (with assets). Liquidity providers earn a fee, provided by the traders. Nowadays, they're earning an additional yield as well named as "yield farming"(Mohan, 2022). However, Smart Contract do not work well for lower liquidity instruments. Therefore, smallholder farmers and crop-growers may find it difficult to implement in spite of its affordability.

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Keynote Presentation: Economics and Adoption of Precision Agriculture

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Presenter Profile

David S. Bullock is a Professor in the Department of Agricultural and Consumer Economics at the University of Illinois. He studies the economics of agricultural technology and information and has published research on precision agriculture technology since 1998. He is the Principal Investigator of the seven-year USDA-sponsored "Data-Intensive Farm Management" project, which uses precision agriculture technology to conduct large-scale, on farm agronomic experiments which generate data to aid farmers' management of nitrogen fertilizer and other inputs. He teaches graduate courses in microeconomic theory. He received his Ph.D. from the Department of Economics at the University of Chicago in 1989.

Do the Extensive Field Experiments in Variable Rate Nitrogen Application Help Farmers make Higher Profits?

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Extended Abstract

Nitrogen (N) fertilizer has been a key input in a corn production all around the rain-fed farms in the U.S. Excessive use of this chemical fertilizer could make severe damage to nearby river and streams and loss on farmer's profit as well. Meanwhile, the deficit of this fertilizer could result in a severe profit loss of farmers due to the undergrowth of the crop in the harvest season. Economically Optimal Nitrogen Recommendation (EONR) is a widely used term in crop productivity and profitability research, and farmer want to achieve this EONR in terms of maximum profits by increasing the nitrogen use efficiency in their fields. To achieve EONR, farmers usually make three different decision. First, some farmers use their knowledge acquired by their experiences. The others buy commercial prescription map for the fertilizer recommendation or apply the results of academic experiments. Farmers who rely on their experience tend to over-apply N which results in profit-loss and environmental damages (Puntel et al. 2016). In case of using commercial or academic recommendation in N application decision, however, all the existing method to achieve EONR are still not highly accurate since the estimating accurate crop nitrogen response entails significant spatial and temporal variability by year and region. Also, the N response process is yet too complex to figure it out by a couple of years short term experiments (Morris 2018).

Maximum return to nitrogen (MRTN) has been developed by seven land grant universities in an early 2000 to provide farmers a more profitable N recommendation by estimating yield response to variable N rate and adjusting N rates with associating crop price and region. However, MRTN derive a single N recommendation rate for each county, and it does not distinguish spatial heterogeneity within county by field characteristics and weather heterogeneity.

On-farm precision experiment (OFPE) uses field specific information such like soil, topography and electro-conductivity in estimating field level crop N response. Farmers are able to adopt information and knowledge about their own field with very low cost of experiments design.

Bullock et al. (2020) simulated thousands of OFPE and compared profitability of OFPE and MRTN when farmer could apply both methods repeatedly for several years. The results of that simulation show that OFPE could be more profitable than MRTN in ten to fifteen years once farmer apply N recommendation system by OFPE and MRTN.

The object of this research is to test if the estimated profit of EONR by using data-driven information of other fields could achieve similar profit with EONR which is achieve by OFPE. With one-year OFPE, we can derive accurate crop N response function in a given farm for a year, but it does not reflect the weather heterogeneity impact on yield N response. Therefore, the estimated EONR by single field OFPE has very limited ability to predict or estimate crop N response in few years at a given field. Once we can achieve the similar profit with EONR by

using other field's OFPE data, we might have better information about how spatial weather heterogeneity affect crop N response estimation. Finally, if the spatial weather heterogeneity has a similar impact on crop N response with temporal weather heterogeneity, we can replace long-term repeated OFPE to estimate how temporal weather condition affect crop N response which requires a large amount of money and a decade long experiments period.

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Keywords

Precision Agriculture, Variable Rate Nitrogen, Machine Learning

Presenter Profile

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Using On-farm Precision Experimentation Data to Analyse Maximum Return to Nitrogen (MRTN) Recommendations

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Abstract

Alternative derivatives of the original yield-goal based recommendations have been employed by researchers, outreach personnel, and private-sector crop management consultants to direct farmers. Current research indicates, however, that the original yield-goal-based method used scant data, questionable data omissions, and flawed statistical analysis. Maximum Return to Nitrogen (MRTN) recommendation is the first publicly available nitrogen recommendation tool to consider economic outcome when recommending nitrogen application rate. However, MRTN adoption is low; farmers may still be following retailer recommendations or prior experience, in part because the nitrogen application rate suggested by the MRTN system is relatively low. This study aims to determine the efficiency of the MRTN recommendations in directing nitrogen application rates in the corn belt. Between 2016 and 2021, forty-two on-farm precision experiments were conducted in Illinois and Ohio to determine the ex-post economically optimal nitrogen rate (EONR), which are used here to evaluate MRTN rates. MRTN rates are compared to the current rates of farmers to determine which achieves relatively high profit margins. Findings suggest that MRTN recommendations can be excessively high or inadequately low across fields in the same region and during the same year. Additionally, grower chosen rates performed better than MRTN on some fields in some regions. Thus, adopting the MRTN recommendation appears riskier than developers claimed.

Keywords

On-Farm Precision Experimentation, Nitrogen Recommendation Tool, Maximum Return to Nitrogen Recommendation

Presenter Profile

A devoted professional with more than 5 years of experience in Digital Agriculture incorporated with rigorous data analytics (R and GIS Software), helping farmers conduct field experiments aiming for superior input rate strategies and higher productivity in 5 countries (the U.S., South Africa, Argentina, Columbia, and Brazil). Has extensive experience leading team-oriented projects facilitating the digital transformation of agriculture in both developed and underdeveloped countries.

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Introduction

To ensure that enough food is produced to feed the world's population, nitrogen fertilizers are required in crops. Nitrogen fertilizers provide crops with minerals like potassium, phosphorus, and nitrogen, which helps plants grow bigger, faster, and produce more food. Nitrogen is present in almost all of the air we breathe, accounting for around 78 percent of it. However, plants require nitrogen compounds from the soil to thrive, which can be supplied either naturally or through nitrogen fertilizers.

The 'Green Revolution' of the 1960s encouraged growers to employ large nitrogen fertilizer inputs in order to get the highest yields possible. Both the introduction of high-yielding crop varieties, as well as lower fertilizer prices, have boosted the usage of nitrogen fertilizers in American agriculture significantly. If crop profitability increased with nitrogen application, increased nitrogen applications would be reasonable. However, nitrogen fertilizer may have been applied excessively due to its low cost. In this case, excessive fertilizer use not only contributes to the release of harmful greenhouse gases and the eutrophication of our waterways, but yield losses and, consequently, profit losses may also occur (Skeffington and Wilson, 1988; Byrnes, 1990; Albornoz, 2016; Kumar et al., 2019).

Due to the uncertainty in soil nitrogen availability and crop nitrogen requirements, farmers face challenges when choosing nitrogen fertilizer rates (Tisdale and Nelson, 1966; Brady et al., 2008). They may find it difficult to apply the appropriate amount of nitrogen because increased nitrogen application without a matching rise in yield leads to profit losses due to the wasted costs, whereas under-applying results in missed profit chances due to lower yield. Numerous nitrogen recommendation tools that advise farmers on how much nitrogen to apply to their fields have emerged as a result of developments in academia and industry.

Development of Nitrogen Recommendation tools

Temperature, rainfall timing, intensity, and amount, as well as temperature and rainfall interactions with nitrogen source, timing, placement, plant genetics, and soil characteristics, make recommending nitrogen rates for a single field or site difficult. As a result, numerous studies have been conducted to investigate better nitrogen management, and various nitrogen rate decision-making models have emerged that generate nitrogen recommendations in the presence of uncertainty in nitrogen supply and demand (Meynard et al., 2002; Lobell, 2007; Setiyono et al., 2011). The goal of these nitrogen recommendation tools is to predict the plant's nitrogen requirements in addition to soil nitrogen.

Prior to the late 1950s, nitrogen rate recommendations were based on soil parameters and crop management (Morris et al., 2018), as soil systems provide a portion of the total nitrogen accumulated by plants. As corn yields increased in the 1980s and 1990s, nearly all nitrogen recommendation systems for corn in the United States endorsed Stanford's proven-yield (PY) method (Stanford, 1966, 1973). Nitrogen prescriptions are based on yield goals in this approach. It quickly became the industry standard in Illinois and many other Midwestern states at the time, with farmers encouraged to follow the rule "1.2 is the maximum" (Fernández et al., 2009). The research conducted by Stanford demonstrated that the amount of nitrogen a plant requires is proportional to its production; specifically, the "optimal" yield level divided by the optimal nitrogen rate resulted in an average of approximately 1.2 pounds of nitrogen per bushel of yield. Most states, using the PY method, would recommend nitrogen rates based on a factor multiplied by yield goal.

The generation of nitrogen application range boils down to understanding the relationship between corn yield and nitrogen fertilization, and (Rodriguez et al., 2019) demonstrated that the yield-goal based recommendation was based on scant data, questionable data omissions, and insignificant and flawed statistical analysis, and thus the linear relationship between corn yield and optimal nitrogen fertilization cannot be trusted. In addition, the nitrogen-to-corn price ratio is not considered in the yield-goal based recommendation system, so this system may not be profitable when fertilizer costs and crop prices fluctuate significantly. For example, given the recent increase in fertilizer costs relative to crop prices, yield-based recommendations may be less profitable, as they were developed when fertilizer was relatively inexpensive.

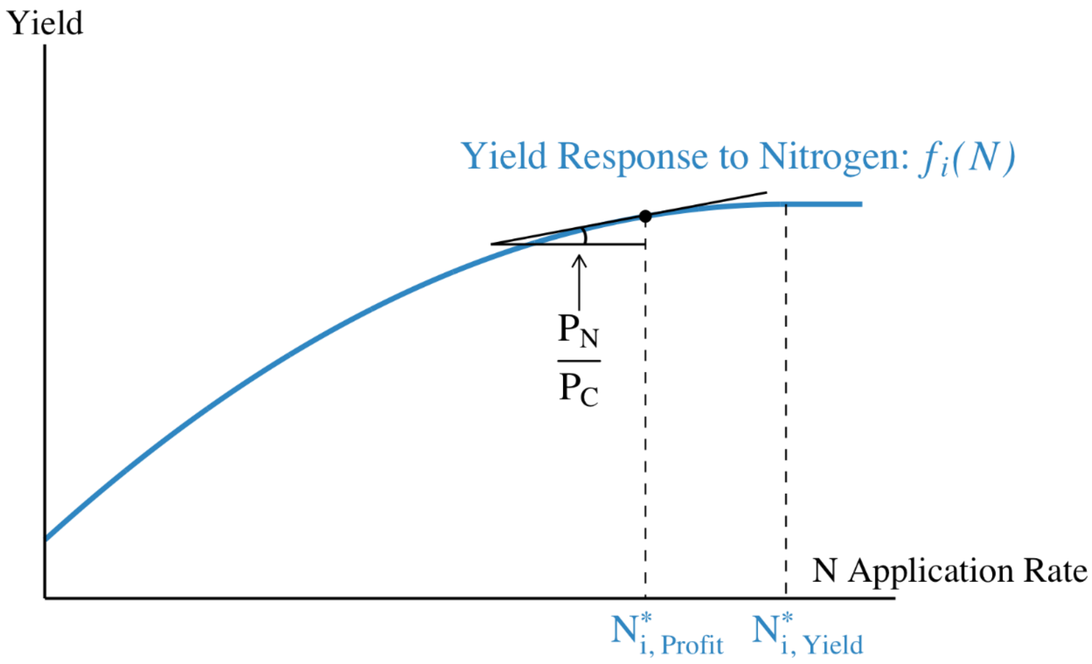

Figure 1: A Conceptual Yield Response to Nitrogen

Figure 1 depicts a currently widely accepted conceptual yield response to nitrogen curve from the standpoint of agronomy. When nitrogen application approaches $Ni, Yield^*$, yield increases until a yield plateau is reached. The subscript i denotes a yield response curve for a specific site i, and the nitrogen yield response curve varies depending on soil parameters and meteorological conditions in that particular year. Although the figure shows that excessive nitrogen application does not always have a negative impact on yield, as shown by the plateau, it can reduce profit. Because yield does not decrease with overapplication and nitrogen costs were not fully considered in its development, the PY method encouraged setting a high yield goal and applying high nitrogen rates, which can cause nitrogen losses in agroecosystems through volatilization, denitrification, leaching, and runoff. As a result, over the last decade, studies have criticized the PY method for resulting in excessively high external environmental costs (Ransom et al., 2020).

Researchers then shifted away from yield-goal based recommendation algorithms due to advancements in hybrids that resulted in higher yields and stronger root systems, as well as changes in the crop-fertilizer price ratio over the past twenty years. Some researchers began to recognize that economics must be factored into a nitrogen recommendation system, and the optimization problem was shifted from finding the $N^{*}_{i,Yield}$ that maximizes yield to solving for the $N^{*}_{i,Profit}$ that maximizes profit (Mamo et al., 2003; Hong et al., 2007). In 2005, seven states implemented the Maximum Return to Nitrogen (MRTN) recommendation system, a relatively new method for estimating the amount of nitrogen required by plants that is not delivered by the soil (Sawyer et al., 2006; Sawyer, 2013; Laboski et al., 2015; Nafziger et al., 2022). They claim to be able to predict the nitrogen rate that will yield the highest return on nitrogen investment based on the corn and nitrogen prices entered into their calculator.

Several changes have occurred in the optimization setting during the development of nitrogen recommendation tools, including a shift in the objective from $Ni, Yield^{*}$ to $Ni, Profit^{*}$; a dramatic shift in corn and nitrogen fertilizer prices in recent years, which has an impact on $Ni, Profit^{*}$ and the evolution of the yield response to nitrogen curve due to advances in seed, soil changes, and other factors. As a result of these changes, the optimal nitrogen rate recommendation has shifted over the last century. The purpose of this research is to examine at the effectiveness of MRTN, which provides nitrogen recommendations based on both nitrogen fertilizer and corn prices, with the objective of maximizing profit.

What is MRTN?

The maximum return to nitrogen, or MRTN, is a data-driven regional approach to nitrogen guidelines used in Iowa, Wisconsin, Illinois, Indiana, Michigan, Minnesota, and Ohio to establish nitrogen recommendation rates. The MRTN system was created by Midwest Land Grant University researchers and has been funded by the Illinois Nutrient Research & Education Council since 2012. The MRTN recommendation is essentially an estimate of EONR that takes nitrogen's return on investment into account (University of Minnesota Extension, 2022), and the MRTN developers claim that this is the first nitrogen recommendation system that takes economics into account in practice. The MRTN tool is open-source and can be found online at Nitrogen Rate Calculator. This online tool hosted by Iowa State University generates nitrogen guidelines based on location, previous crop, corn price, and nitrogen price.

MRTN's Data

The database used in the MRTN method dates back to 1990 and includes data from hundreds of trials. Small-plot trials performed manually, or strip trials may be employed. Six different nitrogen treatment rates are typically planned for strip trials, and each nitrogen rate was applied to three (or more) strips to ensure that the yield variations later detected were due to the variable nitrogen rate.

MRTN attempts to incorporate changes over time as hybrids, new weather conditions, and new management practices emerge by continually adding data to the database. Thus, the database is evolving and reflecting some changes in environmental conditions, hybridization, and other factors. The states of Illinois, Indiana, Iowa, and Wisconsin have been divided into geographic or soil regions, and MRTN recommendations are generated separately for the fields in each region. Thereby, the data used by the MRTN system differ by region, and each region is responsible for gathering its data. As a result, utilizing different databases, distinct yield responses to nitrogen are estimated for different regions.

MRTN's Method

The return to nitrogen (RTN) generated per acre in a trial at a given nitrogen rate is calculated by multiplying the yield increase from nitrogen at that rate (minus the yield without nitrogen fertilizer) by the corn price, then subtracting the cost of nitrogen (the nitrogen rate times the price of nitrogen). The MRTN approach calculates the return to nitrogen (RTN) across a variety of nitrogen rates by fitting a curve using nitrogen trial data acquired from different research locations, and RTN for a state or region will then be estimated by averaging the fitted curves from all trials within that state or region.

Individual curves comparing nitrogen application rates (lb/ac) versus RTN ($/ac) are constructed for different regions and preceding crops, and the nitrogen rate corresponding to the maximum RTN across trials in a region/state is the "Maximum Return to Nitrogen" for that region/state. The MRTN system also provides a profitable nitrogen rate range, which is defined as the nitrogen rates above and below the MRTN rate resulting a -$1/ac difference in RTN when compared to the RTN associated with the MRTN rate (Dr. Emerson Nafziger, 2018; University of Minnesota Extension, 2022).

Developers of the MRTN approach claim that they incorporate all variables affecting nitrogen response into the MRTN recommendation through including in yield response estimation model: weather conditions, soil types, and a variety of other characteristics. The R^2 reported for the yield response estimation model is approximately 0.57 (University of Minnesota Extension, 2022).

Discussions over MRTN

The three most important advantages of the MRTN system were emphasized by the system's developers. First, because the database is regularly updated, it is a dynamic model that captures changes in weather and soil. Second, because the profitable range of MRTN allows farmers to select alternative rates on their own fields, it is flexible and adaptive and allows for the customization of nitrogen rates applied to a specific field. Furthermore, the calculation can consider different pricing scenarios, and this is meaningful given the recent changes in corn and nitrogen prices, as well as the fact that different farmers buy fertilizer and sell corn at different prices.

Despite the negative effects on water quality and the ecosystem, as well as the potential benefits of following the MRTN recommendations, (Sellars et al., 2021) discovered that 70 percent of corn fields receive nitrogen applications above the MRTN profitable range using field-level data from Precision Conservation Management (PCM), a farmer service program led by the Illinois Corn Growers Association and Illinois Soybean Association.

Given that the profit maximizing nitrogen rate, varies across fields and over time due to interactions between soil and weather conditions [Bundy and Andraski (1995); Mamo et al. (2003); schmitt1994developing; lory2003yield; dhital2016variability], the MRTN system's failure to differentiate its recommendations on different fields within the designated region may have weakened farmers' confidence in the MRTN recommendations. Additionally, the MRTN system also lacks some transparency by not sharing the EONR calculated for the individual sites used for their regional recommendation; thus, the farmers cannot see how varied the EONRs may be in their region. Furthermore, if the true optimal nitrogen rate is not included in the experimental nitrogen range, the MRTN recommendations will be either too high or too low. Finally, farmers may find following the MRTN recommendations to be risky, because they are sometimes lower than the nitrogen rates farmers have been using in the past.

The developers of MRTN propose as a solution to the first problem that farmers can experiment on their farm within the MRTN profitable range and estimate the optimal rate on their own (University of Minnesota Extension, 2022). However, farmers may find it challenging to design and analyze meaningful experiments. To determine why farmers are hesitant to use the MRTN recommendations and whether farmers should follow the MRTN recommendations, however, real trial experiments must be employed to investigate the effectiveness of the MRTN approach in guiding nitrogen application.

Given that MRTN is still a relatively new method, the majority of studies examining the MRTN approach are conducted by the developers of the MRTN system. The major flaws of MRTN approach summarized from these studies include the fact that year-to-year temperature and precipitation variations are not addressed in the recommendations and within-field spatial heterogeneity due to soil and water quality is not considered, both of which are already evident from the method's description. Using EONR derived from small-plot trials and reviewing eight nitrogen recommendation tools, including the MRTN approach, (Ransom et al., 2020) determined that the MRTN recommendations overestimated EONR by 14 to 17 lb per acre on average. Together, the findings of (Ransom et al., 2020) and (Sellars et al., 2021) are concerning, as they indicate that 70 percent of the fields in Illinois received nitrogen applications that exceeded the MRTN recommendations, which were already higher than EONR. This is both economically and environmentally harmful.

(Ransom et al., 2020) also pointed out one weakness of the MRTN system being it cannot provide recommendation for a particular weather year. However, this critique can be too strict, as no one can predict weather, and MRTN system has made good effort in including data from multiple years to embed different weather conditions in its estimation. Nonetheless, another concern that has not been addressed in the existing literature is that MTRN combining trials dated back to 1990s in the same region can be risky. First, MRTN system lacks transparency in how trials are designed, and if trials within a region do not receive identical experimental nitrogen rates, they are not comparable to each other, and thus, should not be merged together for analysis. Second, data from 1990s should not be used to estimate the current nitrogen recommendation rate because we no longer use the hybrid from 30 years ago. Therefore, the 1990s data does not accurately reflect the current relationship between yield and nitrogen.

Objectives

The quality of nitrogen recommendations made to farmers is restricted by the estimation of the yield response to nitrogen. In order to properly evaluate the MRTN recommendations, it is necessary to use real trial data from the same site and different years that have been properly processed. While Ransom et al. discovered that MRTN rates are, on average, higher than EONR rates (2020). First, the EONR was derived using data from small-plot trials that do not accurately represent entire fields. Second, neither the profitability of MRTN rates nor its profitable range were evaluated. Thirdly, only one model was used to estimate the EONR, despite the fact that the EONR is sensitive to the production model used for estimation.

In recent years, agricultural scientists have increasingly designed and implemented a modern type of agronomic field experiment known as on-farm precision experimentation (OFPE). OFPE brings together researchers and farmers to undertake agronomic studies, using variable-rate input technology and GPS to automate the application of designed nitrogen rates across multi-hectare agricultural fields and yield monitors to collect yield data at harvest.

The overarching objective of this study is to evaluate the MRTN recommendations, including the MRTN rates and their profitable range, using data from forty-two OFPE trials. Specifically, we estimate the ex-post EONR for each of the forty-two OFPE trials and use the estimated yield response to nitrogen to assess the profitability of the MRTN recommendations. In addition, the profit performance of the farmers' chosen rates is compared to MRTN rates. To test for robustness, yield response to nitrogen was estimated using various models.

Methods

Data Description

The datasets used for this research come from twelve different farms, including forty-two separate field-year corn trials, as shown in Figure 2. Among the twelve farms, three are in northern Illinois, four are in central Illinois, three are in southern Illinois, and two are in Ohio. Specifically, nine field-year experiments were conducted in northern Illinois, twelve field-year trials were conducted in Central Illinois, fourteen field-year trials were conducted in southern Illinois, and seven field-year trials were conducted in Ohio. All trials are in locations with MTRN guidelines.

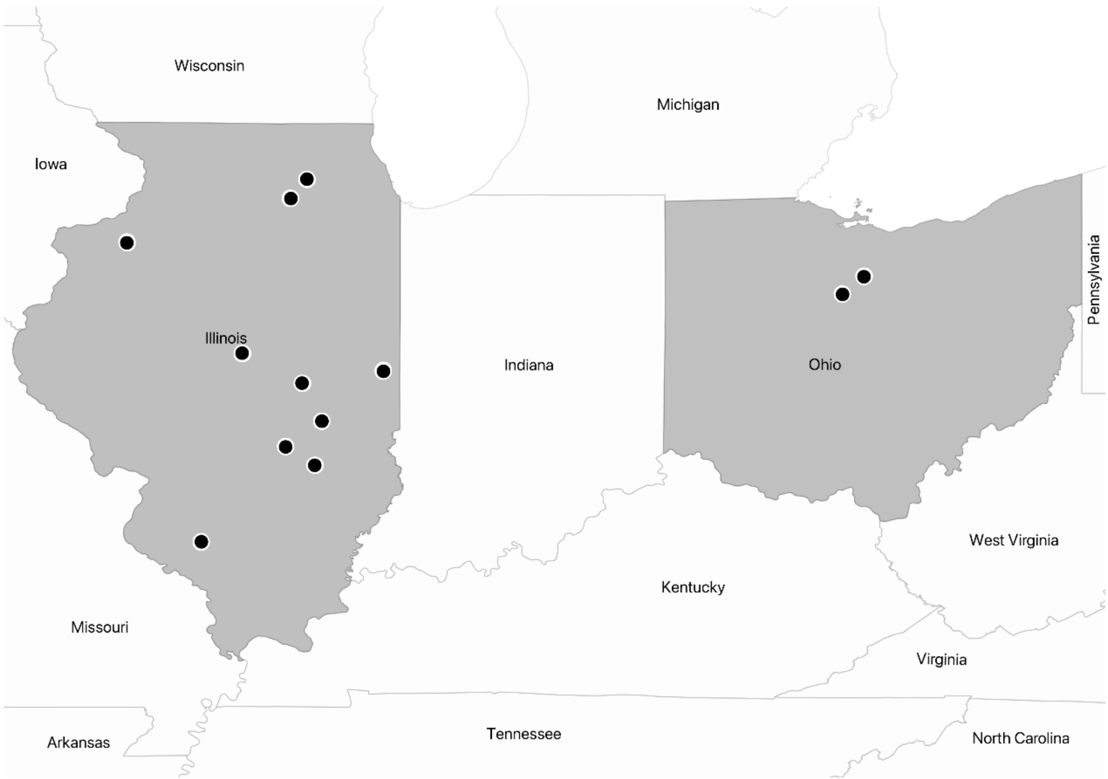

Figure 2: Distribution of the Forty-two Trials

Data Processing

Raw as-applied and harvest data were retrieved from the variable-rate applicators and yield monitors. The raw data were cleaned to remove observations with extreme yield or as-applied rates ("outliers"). Points were also removed from the headlands, where the data is less reliable due to differences in sun exposure, driving speeds, potential application overlaps, and other factors. The distance between points, swath width, and headings recorded in the raw yield data was used to make yield polygons, and subplots were made by combining contiguous yield polygons with similar nitrogen rates into groups, where the number of yield polygons combined should make a subplot of around twelve meters in length. (In later analysis, the subplots were used as the unit of observation.)

When the standard deviation of the treatment values at points within a yield polygon was below 40 lbs/ac of nitrogen and 10K seed, the polygon was considered as not having mixed treatments. This means that the yield observation came from mostly one of the treatments. Yield polygons from mixed treatments are not included in the future processing steps or analysis. The yield polygons are grouped where adjacent as-planted polygons are in the same group if the difference in their treatment rates is below a given threshold. This method also helps to eliminate "transition zones," which are areas where the harvester and planter are adjusting to a new target rate or yield level when moving from one treatment plot to another. The mean as-planted rate and yield for each subplot are recorded. Finally, the means of electrical conductivity, SSURGO soil data, and USGS digital elevation data are recorded for each subplot. In addition, digital elevation maps are used to calculate the values of topographical aspect, slope, curvature, topographical position index, and topographical wetness index, and the means of these values are included in the data for analysis.

Historical corn and nitrogen prices from 2015 to 2021 are used to obtain the MRTN recommendation for all the trials, specifically, the historical corn prices come from the website Macrotrend, and the historical nitrogen prices are from DTN. Table 1 summarizes the historical corn and nitrogen prices used for each year.

Table 1: Historical Corn and Nitrogen Prices used in this Research

Year	Corn Price ($/bu)	Nitrogen Price ($/lb)	Nitrogen/Corn Price Ratio
2015	3.81	0.42	0.11
2016	3.53	0.35	0.10
2017	3.48	0.24	0.07
2018	3.66	0.32	0.09
2019	3.92	0.36	0.09
2020	4.17	0.33	0.08
2021	6.29	0.80	0.13

The MRTN for the forty-two trials in different regions and years are summarized in Table 2. Trials in the same region and year have identical MRTN recommendation rates, as well as profitable range. Table 3 presents the descriptive statistics for the trial data. To evaluate the MRTN recommendations, we only use the EONR derived from trials that received experimental nitrogen ranges that cover the MRTN rate.

Table 2: MRTN recommendation for the forty-two trials in different regions and years

Farm	Field	Year	MRTN (lb/ac)	MRTN Low (lb/ac)	MRTN High (lb/ac)
Region: Central Illinois					
GI	Field1	2018	196	178	213
	Field2	2017	182	167	197
		2019	186	171	202
OV	Field3	2017	182	167	197
RO	Field4	2018	196	178	213
	Field5	2020	184	170	200
	Field6	2016	177	164	191
SA	Field7	2016	177	164	191
		2018	196	178	213
		2020	184	170	200
	Field8	2017	182	167	197
		2021	190	175	206
Region: Northern Illinois					
GO	Field9	2019	178	160	195
	Field10	2020	175	159	192
LA	Field11	2020	175	159	192
	Field12	2017	181	155	188
	Field13	2018	188	169	207
NE	Field14	2021	182	165	199
	Field15	2017	181	155	188
		2021	182	165	199
	Field16	2020	175	159	192
Region: Southern Illinois					
BO	Field17	2016	195	183	210
		2018	217	198	239
		2020	204	189	220
	Field18	2016	195	183	210
		2018	217	198	239
		2020	204	189	220
CA	Field19	2017	200	186	217
		2019	206	191	224
	Field20	2019	206	191	224
		2021	210	194	228
WE	Field21	2017	200	186	217
		2019	206	191	224
		2021	210	194	228
	Field22	2018	217	198	239
Region: Ohio					
HO	Field23	2021	192	175	210
	Field24	2018	200	179	219
		2020	185	168	202
	Field25	2017	180	163	198
		2019	186	169	205
		2021	192	175	210
NI	Field26	2018	200	179	219

Note: In addition to the MRTN rate, the MRTN website provides nitrogen rate ranges that could be considered profitable nitrogen ranges because nitrogen rates within this range would produce a net return of less than -$1/acre when compared to the MRTN rate. The low and high ends of the MRTN profitable range are termed as MRTN low and MRTN high in this table.

Table 3: Descriptive Statistics for the forty-two trials

Farm	Field	Year	Dry Yield (bu/ac)[5] Mean	First Decile	Ninth Decile	SD	Applied Nitrogen (lb/ac)[6] Mean	First Decile	Ninth Decile	SD
Region: Central Illinois										
GI	Field1	2018	249.6	237.9	260.8	9.2	187.8	150.2	223.8	23.4
	Field2	2017	234.9	218.5	252.3	13.4	199.2	169.7	229.2	21.1
		2019	206.8	192.4	220.9	11.1	193.0	141.1	236.8	41.2
OV	Field3	2017	229.2	213.4	243.4	11.9	177.0	155.8	197.5	14.6
RO	Field4	2018	217.3	180.0	248.8	30.2	205.9	187.3	226.6	14.6
	Field5	2020	247.7	224.1	267.4	18.2	173.4	131.8	214.2	28.9
	Field6	2016	228.9	212.8	244.9	12.7	190.4	160.3	217.5	17.7
SA	Field7	2016	220.5	210.6	231.3	16.7	190.1	160.0	220.0	20.7
		2018	254.4	230.7	279.4	19.5	204.8	192.0	217.1	8.3
		2020	245.0	230.4	257.9	11.3	211.9	162.5	255.2	31.4
	Field8	2017	224.7	211.2	241.4	13.7	254.8	225.4	282.3	22.5
		2021	237.5	197.4	264.3	25.7	181.4	141.5	226.6	33.1
Region: Northern Illinois										
GO	Field9	2019	185.9	157.1	210.8	21.1	183.6	139.4	240.4	37.4
	Field10	2020	175.3	124.0	225.8	43.2	184.4	150.8	220.4	27.5
LA	Field11	2020	185.6	169.7	200.7	12.9	193.0	181.3	201.9	8.1
	Field12	2017	345.4	311.5	375.7	25.3	180.4	147.0	212.0	22.0
	Field13	2018	240.0	198.2	273.4	29.6	202.8	179.6	229.8	17.4
	Field14	2021	200.2	128.4	260.8	51.8	178.9	119.4	238.4	40.2
NE	Field15	2017	262.0	238.1	288.2	20.9	181.5	147.3	210.3	22.6
		2021	223.7	192.9	252.8	23.2	167.2	119.3	224.7	38.5
	Field16	2020	224.2	198.2	245.2	19.4	180.0	134.7	222.6	28.5
Region: Southern Illinois										
BO	Field17	2016	138.1	92.6	180.4	36.5	170.1	140.0	200.0	19.0
		2018	174.0	123.4	219.6	36.3	175.4	151.8	193.4	14.4
		2020	143.6	84.2	189.3	40.4	220.7	176.8	267.3	34.3
	Field18	2016	129.0	84.6	172.1	34.1	169.1	139.1	198.5	18.9
		2018	205.3	170.5	235.9	25.1	178.5	157.2	195.4	13.5
		2020	143.8	89.2	190.8	39.2	203.0	162.9	247.4	31.9
	Field19	2017	172.6	131.4	206.8	29.5	202.5	176.2	227.7	19.2
		2019	134.6	98.8	172.9	28.0	183.5	132.8	223.9	35.7
CA	Field20	2019	159.5	132.6	189.3	21.7	188.5	141.0	235.7	34.4
		2021	189.2	164.9	213.4	18.8	150.2	100.9	183.8	35.3
WE	Field21	2017	230.3	210.4	249.6	15.1	196.9	160.2	223.3	21.1
		2019	205.3	167.2	240.8	28.9	213.4	162.6	257.1	35.6
		2021	247.6	215.1	280.9	25.4	242.6	190.4	308.8	45.9
	Field22	2018	235.8	206.0	262.3	22.0	175.0	160.0	197.1	14.7
Region: Ohio										
HO	Field23	2021	199.0	181.3	214.6	13.5	219.9	158.7	269.8	40.2
	Field24	2018	237.2	218.3	253.1	14.8	166.1	146.8	183.3	13.9
		2020	241.9	219.4	260.4	16.3	217.7	184.5	250.9	26.8
	Field25	2017	233.4	217.1	250.5	14.2	191.5	172.2	208.5	13.2
		2019	185.5	163.1	205.1	16.7	204.6	179.6	235.4	23.1
		2021	213.8	183.9	242.0	22.6	221.3	158.4	272.0	39.4
NI	Field26	2018	240.8	215.6	265.9	19.7	215.3	190.6	240.7	18.0

[5] This column provides an overview of the cleaned dry yield volume data, including the mean, first decile, ninth decile, and standard deviation.

[6] This column provides an overview of the cleaned applied nitrogen data, including the mean, first decile, ninth decile, and standard deviation.

EONR Calculation

The optimal nitrogen rate denotes the rates of nitrogen application expected to maximize net revenues from nitrogen applied per unit of land area. Specifically, the optimal nitrogen rate is obtained by solving the following objective function:

$$\text{Max}\{P_C f(N) - P_N N\} \quad (1)$$

In equation (1), P_C denotes the price of corn ($/bu), and P_N denotes the price of nitrogen ($/lb).

This study estimates the production function $f(N)$ for each of the thirty-eight trials and determines the optimal nitrogen rate for each trial. Then, we compare the online MRTN recommendation to the optimal nitrogen rate estimations to determine how far off the MRTN recommendation is in these trials. In addition, we analyze the profitability of the MRTN recommendation by substituting the MRTN recommendations into the estimated production function $f(N)$ and comparing the resulting profit to the maximum profit derived from this production function.

Generalized Additive Model (GAM)

Because researchers do not know the true functional form of the yield response to nitrogen, the generalized additive model (GAM) is used in the estimation of yield response to nitrogen to better capture the curvature of the function.

The generalized additive model (GAM) contains a parametric form for some components of the data with weak nonparametric restrictions on the remainder of the model. Letting ϕ_k denote the k^{th} cubic spline, then the parametric form of the non-linear function is $\sum_{k=1}^{K} \beta_k \phi_k(N_i)$, where$\beta_k$ are parameters to be estimated. Let ε denote the remainder of the model, following the conditional mean restriction on ε: $E(\varepsilon|N) = 0$. Thus, the estimating equation is:

$$y_i = \sum_{k=1}^{K} \beta_k \phi_k(N_i) + \varepsilon_i \quad (2)$$

Results

Profitability of MRTN Recommendations

Table 4 summarizes the profit difference between applying optimal nitrogen rates estimated by GAM and applying MRTN recommendations, as well as the profit difference between using grower-chosen rates and MRTN nitrogen rates. In general, the larger the number on the number, the less profitable the MRTN recommendations are in comparison to the estimated optimal nitrogen rates and grower-chosen rates. According to the MRTN definition and its profitable range, the difference in value between any two of these three columns should be less than $1/ac. However, we find that the difference between these three columns is almost always much greater than $1/ac. In terms of profitability, this indicates that following the MRTN recommendations is significantly riskier than what the developers claim.

Table 4: Profit difference estimated by GAM

Farm	Field	Year	MRTN ($/ac)[a]	MRTN Low ($/ac)[b]	MRTN High ($/ac)[c]	Grower Chosen Rate ($/ac)[d]
Region: Central Illinois						
GI	Field1	2018	2.3	0	7.7	2.2
	Field2	2017	0	0.4	0.4	-1.6
		2019	0	1.5	0.9	-10.4
OV	Field3	2017	6.1	13.3	1.2	-0.8
RO	Field4	2018	21.7	37.4	9.4	10.4
	Field5	2020	12.6	16.4	8	-1.2
	Field6	2016	13	17.2	8.5	6.9
SA	Field7	2016	10.5	2.6	16	-6.7
		2018	17.2	30.4	4.5	10.4
		2020	7.8	14.4	2.3	7.3
	Field8	2017	NA	NA	NA	NA
		2021	7.6	25.2	0.1	6
Region: Northern Illinois						
GO	Field9	2019	3.4	9.6	0.4	0.5
	Field10	2020	4.5	3	6.2	-1.1
LA	Field11	2020	6.5	NA	9.3	-2.9
	Field12	2017	23.5	66	15.9	11.2
	Field13	2018	14.8	9.2	13.3	-0.4
NE	Field14	2021	44.1	36.2	48.2	0.4
	Field15	2017	5.8	2.1	5.6	0.1
		2021	14	10.2	17.7	0.2
	Field16	2020	7.4	17.1	1.5	2.5
Region: Southern Illinois						
BO	Field17	2016	4.6	0.6	11	4.5
		2018	NA	NA	NA	NA
		2020	11.9	20.4	5.3	4.9
	Field18	2016	0.8	3.8	NA	-3.8
		2018	NA	NA	NA	NA
		2020	7.2	8.9	5.4	1.2
	Field19	2017	77.5	107	41.8	-84
		2019	41.8	57.9	22.2	4.3
CA	Field20	2019	10.2	19.1	4	-8.3
		2021	NA	NA	NA	NA
WE	Field21	2017	12.7	18.7	5.3	248.2
		2019	53.3	80	28.9	118
		2021	89.6	120	58.8	60.7
	Field22	2018	53.9	15.7	108.4	53.8
Region: Ohio						
HO	Field23	2021	11.8	6.9	16.9	1.4
	Field24	2018	8.4	1.5	15.1	-32
		2020	13.4	23	5.6	1.1
	Field25	2017	1.2	NA	4.5	-1.5
		2019	11.2	22.1	2.8	-14.8
		2021	4	14.1	0	-19.4
NI	Field26	2018	23	42.4	9.1	-18.5

Note: When the MRTN rate is outside the trial's applied nitrogen rate range, the estimated profit difference will be NA in all four columns because the MRTN rate cannot be evaluated using the trial's data. While the MRTN rate is within the trial's applied nitrogen rate range and is being evaluated, the value in columns MRTN Low and MRTN High may be NA in some cases as MRTN Low and MRTN High may fall outside the nitrogen application of that trial.

[a]The profit difference between applying the MRTN rates obtained from the MRTN website and applying the optimal nitrogen rate determined by the GAM model is shown in this column.

[b]The profit difference between using the recommended nitrogen rate determined by the GAM model and the lower end of the MRTN profitable range is shown in this column.

[c]The profit difference between using the recommended nitrogen rate determined by the GAM model and the higher end of the MRTN profitable range is shown in this column.

[d]This column displays the profit difference between applying the grower chosen rates and applying the MRTN rates from the MRTN website. Grower chosen rates outperforms the MRTN rates when that value is positive.

Figure 3 demonstrates, for instance, that in field 19, there is a significant yield response to nitrogen, and the optimal nitrogen rates shown in Table 95 suggested applying a similarly high nitrogen rate to that field in 2017 and 2019. However, the MRTN recommendation must have underestimated the slope of the yield response to nitrogen increment on the field because it recommended a profitable nitrogen range with nitrogen rates 50 to 20lb/ac below the estimated optimal nitrogen rates, resulting in a profit loss of $107/ac to $22/ac. Furthermore, in twenty-three of the forty-two trials, grower-chosen rates outperformed MRTN rates. In other words, more than fifty percent of the time, MRTN rates do not provide a profitable advantage over grower-chosen rates, despite their claim to be the lowest possible nitrogen rate that provides the highest returns.

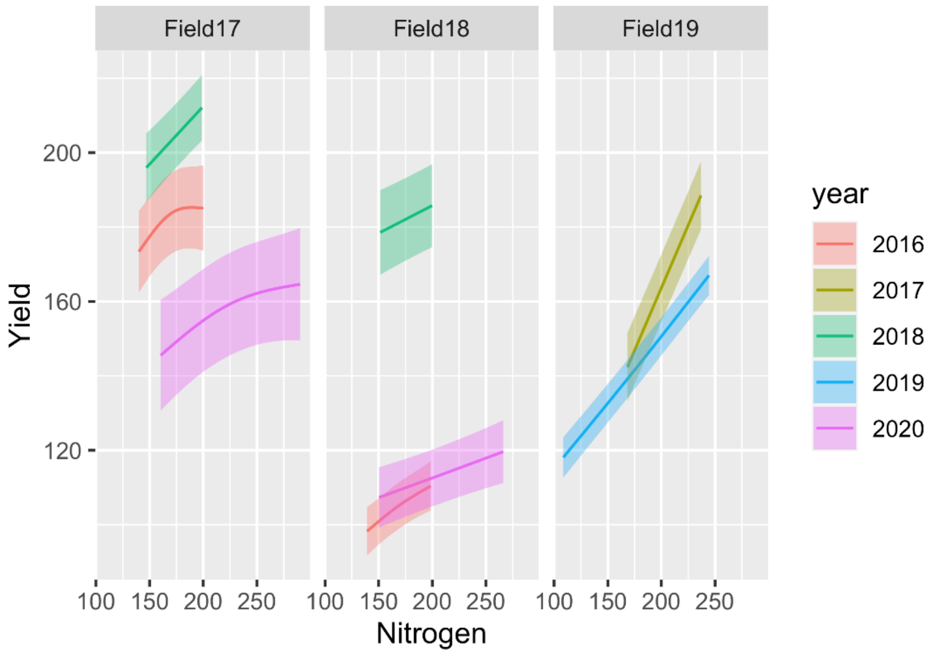

Figure 3: Estimated Yield Response to Nitrogen on Farm BO (GAM Model)

We also compare the optimal nitrogen rates estimated by GAM to the MRTN recommendations in Table 5 for thirty-eight trials to determine whether the MRTN recommendation is consistently higher or lower than the optimal nitrogen rate estimates. In thirty-one of thirty-eight trials, the estimated optimal nitrogen rates differ from the MRTN rates by tens of pounds per acre and are also outside the MRTN profitable range. Twenty-three of the thirty-one trials have estimated optimal nitrogen rates that are higher than the profitable range provided by the MRTN website, while eight have estimates that are lower. The MRTN recommendation is neither consistently higher nor lower than estimates of the optimal nitrogen rate. Depending on the soil and climate, the MRTN recommendation may be excessively high or insufficient.

Table 5: Optimal nitrogen rates estimated by GAM

Farm	Field	Year	MRTN (lb/ac)[a]	GAM (lb/ac)[b]	Grower Chosen Rate (lb/ac)[d]
GI	Field1	2018	196 (178, 213)	176.8	180
GI	Field2	2017	182 (167, 197)	184.7	210
GI	Field2	2019	186 (171, 202)	188.9	235
OV	Field3	2017	182 (167, 197)	201.4	180
RO	Field4	2018	196 (178, 213)	231.1	210
RO	Field5	2020	184 (170, 200)	226.8	179.6
RO	Field6	2016	177 (164, 191)	217.7	198.5
SA	Field7	2016	177 (164, 191)	160	200.3
SA	Field7	2018	196 (178, 213)	219	210
SA	Field7	2020	184 (170, 200)	219.5	210
SA	Field8	2017	182 (167, 197)	NA	198.3
SA	Field8	2021	190 (175, 206)	208.8	200
GO	Field9	2019	178 (160, 195)	204.7	180
GO	Field10	2020	175 (159, 192)	128.5	186
LA	Field11	2020	175 (159, 192)	203	180
LA	Field12	2017	181 (155, 188)	212	192
LA	Field13	2018	188 (169, 207)	231.6	192
NE	Field14	2021	182 (165, 199)	118.2	181
NE	Field15	2017	181 (155, 188)	146.4	187.2
NE	Field15	2021	182 (165, 199)	118.6	181
BO	Field16	2020	175 (159, 192)	208.1	180.7
BO	Field17	2016	195 (183, 210)	177.6	180
BO	Field17	2018	217 (198, 239)	NA	180
BO	Field17	2020	204 (189, 220)	253.6	215
BO	Field18	2016	195 (183, 210)	198.5	180
BO	Field18	2018	217 (198, 239)	NA	198

Farm	Field	Year	MRTN (lb/ac)[a]	GAM (lb/ac)[b]	Grower Chosen Rate (lb/ac)[d]
CA	Field19	2020	204 (189, 220)	266.1	215
		2017	200 (186, 217)	236.9	160
		2019	206 (191, 224)	244.3	210
	Field20	2019	206 (191, 224)	250	191.9
		2021	210 (194, 228)	NA	180
WE	Field21	2017	200 (186, 217)	228.9	757.5
		2019	206 (191, 224)	268.4	863.4
		2021	210 (194, 228)	306	250
	Field22	2018	217 (198, 239)	178.7	180
HO	Field23	2021	192 (175, 210)	150.9	(172.2,196.8)
	Field24	2018	200 (179, 219)	168.5	(75.7,95.6)
		2020	185 (168, 202)	230.9	(180.4,196.8)
	Field25	2017	180 (163, 198)	166.6	189.9
		2019	186 (169, 205)	224.7	(155.8,180.4)
		2021	192 (175, 210)	210.4	(155.8,180.4)
NI	Field26	2018	200 (179, 219)	242	180

Note: All four models' estimates of the optimal nitrogen rate will be NA when the MRTN rate is outside the trial's applied nitrogen rate range because the MRTN rate cannot be compared to the estimations in that situation.

[a]This column provides the MRTN rates obtained from the MRTN website, and the profitable range is presented below the MRTN rates.

[b]This column provides the optimal nitrogen rate estimated by the gam model.

[d]The grower chosen rates are shown in this column. When a commercial prescription map is available, a range is given, and when a farmer is adhering to a previous rate, a single rate is given. When the grower selected rates are significantly lower than in other fields and years, a base rate farmer would have been applied in advance, but we are unsure of what the base rate would have been.

The findings from the current analysis can be summarized as: (1) the MRTN does not follow the same trends as the GAM estimations. For example, in 2020 Field 25 had higher EONRs than in 2018, but the MRTN recommendation was lower in 2020 than in 2018 (2) MRTN recommendation is not consistently higher or lower than the EONR estimates. The MRTN recommendation can be both too high or too low, depending on the soil and weather year. (3) the EONR estimates for Field 23 and Field 25 are very different in the 2021 trials despite these being adjacent fields. The EONR estimation suggests a lower nitrogen rate on Field 23 in 2021 and a higher nitrogen rate on Field 25; (4) while the MRTN recommendation fluctuated within 20lb/acre across the three fields over the years in this farm, the estimated EONR using both yield estimation models varied by more than 60lb/acre on Field 24 during the two trial years, as shown in Table 4.

Trials with the identical MRTN Recommendations

The differences in MRTN recommendations for different fields over time within the same designated region are due entirely to the difference in corn and nitrogen prices entered into the MRTN calculator, without considering the variation in soil and weather conditions between fields and years. As part of our evaluation of the MRTN recommendations, we assess the soil and climate variation between fields in the same region over time, in addition to comparing the estimated optimal nitrogen rates on fields in the same region and year to the MRTN recommendation they receive.

Table 2 shows that the mean yield in different fields within the same MRTN designated region and during the same year can vary significantly despite receiving a comparable range of nitrogen application. Field 10 and field 16 are both located in Northern Illinois; however, the average yield on field 10 in 2020 is only 175bu/ac, while the average yield on field 16 in 2020 is as high as 224bu/ac. The weather conditions on these two fields in 2020 from Table 6 indicate that field 10 experienced significantly less precipitation during the pollination cycle and significantly more precipitation during the grain filling cycle than field 16. During these two periods, the temperature in field 16 was higher than in field 10. Field 10’s yield may have been reduced as a result of hotter weather and less precipitation during pollination. In the absence of additional information, the soil conditions and weather conditions in these two fields are likely to be significantly different; thus, the optimal nitrogen rates for these fields in 2020 are also likely to vary as well. In this case, adhering to the MRTN recommendation and applying similar nitrogen rates to these two fields in 2020 could result in a catastrophic loss of profits. In fact, Figures 10.8 and 10.10 demonstrate low yield response to nitrogen on field 10 in 2020, and significant yield response to nitrogen increasing from 125lb/ac to 225lb/ac on field 16 in 2020, followed by a yield plateau. Estimated optimal nitrogen rates by GAM for field 10 were 128lb/ac, and 208lb/ac for field 16, nearly double that of field 10.

In addition, an example from HO farm shows that the optimal nitrogen rates vary on adjacent fields within the same farm and the same year. Field 23 and Field 25 are neighboring fields on the farm HO. Despite being only one mile apart, according to Table 6, field 25 received more precipitation than field 23 in 2021. Table 3 also indicates that the average yield on field 25 was higher in 2021. Figure 4 illustrates a linear yield response to nitrogen on field 23, resulting in a corner solution of 151lb/ac for the optimal nitrogen rate on this field; a higher yield response to the nitrogen with a quadratic shape was observed on field 25, and the optimal nitrogen rate is 210lb/ac, as shown in Table 5. The MRTN recommendations for this farm do not reflect the estimated changes in optimal nitrogen rates. Specifically, the MRTN recommendations did not vary by more than 20lb/ac across the three fields in this farm over the years, whereas the estimated optimal nitrogen rates using both yield estimation models varied by more than 60lb/ac on field 24 over the two trial years.

Table 6: Weather for the forty-two trials

Farm	Field	Year	Precipitation (in)[a]			Temperature (°F)[b]		
			Pollination Cycle	Grain Filling Cycle	Growing Season	Pollination Cycle	Grain Filling Cycle	Growing Season
Region: Central Illinois								
GI	Field1	2018	1.4	6.8	14.1	77.1	74.5	73.3
	Field2	2017	2.9	4.5	19.0	77.0	71.2	69.9
		2019	0.3	6.7	19.4	78.4	73.6	73.3
OV	Field3	2017	1.4	5.4	22.4	75.2	73.5	70.0
RO	Field4	2018	1.7	7.5	19.0	76.6	74.0	73.0
	Field5	2020	3.4	3.4	14.8	73.6	67.2	70.5
	Field6	2016	5.1	10.0	22.1	74.7	75.4	71.4
SA	Field7	2016	4.5	10.7	21.4	76.8	76.2	72.1
		2018	1.6	5.2	15.1	76.6	74.4	73.2
		2020	2.3	3.6	9.2	74.8	70.4	72.8
	Field8	2017	2.2	4.0	11.5	76.8	70.5	70.0
		2021	3.3	5.7	18.7	72.7	74.4	71.4
Region: Northern Illinois								
GO	Field9	2019	0.5	14.9	21.1	72.0	67.2	69.4
	Field10	2020	0.6	7.6	24.3	74.3	65.9	67.6
LA	Field11	2020	2.0	8.0	19.1	73.2	66.8	67.9
	Field12	2017	6.2	8.6	21.3	71.5	66.9	65.3
	Field13	2018	1.1	8.0	23.7	73.0	71.1	69.8
NE	Field14	2021	4.0	7.9	23.5	70.9	73.5	69.6
	Field15	2017	3.5	3.0	12.6	74.3	68.0	69.9
		2021	3.7	5.9	22.5	71.6	73.7	70.2
	Field16	2020	1.1	4.6	23.4	78.5	74.3	53.2
Region: Southern Illinois								
BO	Field17	2016	4.9	12.3	22.1	74.9	77.9	73.3
		2018	3.5	8.9	19.1	77.6	76.6	75.6
		2020	0.4	11.5	19.4	78.8	75.4	72.1
	Field18	2016	4.9	12.3	22.1	74.9	77.9	73.3
		2018	3.5	8.9	19.1	77.6	76.6	75.5
		2020	0.4	11.5	19.4	78.8	75.4	72.1
CA	Field19	2017	0.7	4.9	16.2	78.3	74.5	72.0
		2019	1.1	7.2	22.5	79.9	76.3	72.9
	Field20	2019	0.6	5.7	16.4	80.6	77.2	73.6
		2021	2.3	10.4	19.6	77.2	76.5	71.9
WE	Field21	2017	1.7	4.5	22.0	77.7	73.0	70.1
		2019	0.9	9.8	24.2	79.3	74.4	74.0
		2021	5.4	9.3	21.8	74.9	75.0	71.8
	Field22	2018	2.1	11.1	21.6	77.5	76.0	74.5
Region: Ohio								
HO	Field23	2021	3.3	6.8	17.2	73.0	72.4	71.9
	Field24	2018	1.8	5.7	15.2	75.2	72.9	71.5
		2020	5.2	9.2	15.4	73.6	66.3	69.8
	Field25	2017	4.5	5.3	22.9	74.6	68.9	67.0
		2019	2.2	5.0	17.4	75.6	70.9	71.5
		2021	5.6	9.6	22.6	74.0	73.1	69.1
NI	Field26	2018	0.7	5.3	14.5	74.5	73.1	71.5

Note: The hybrid that was planted for each trial is recorded, and the breeders' websites commonly offer an estimation of the growing degree days until pollination and maturity. Using this information, the planting date, and the daily weather data from DaymetR, we determine the pollination and maturity dates for each trial. The weather is then calculated around the critical growth stages, and its impacts on the estimation of the optimal nitrogen rates can be examined.

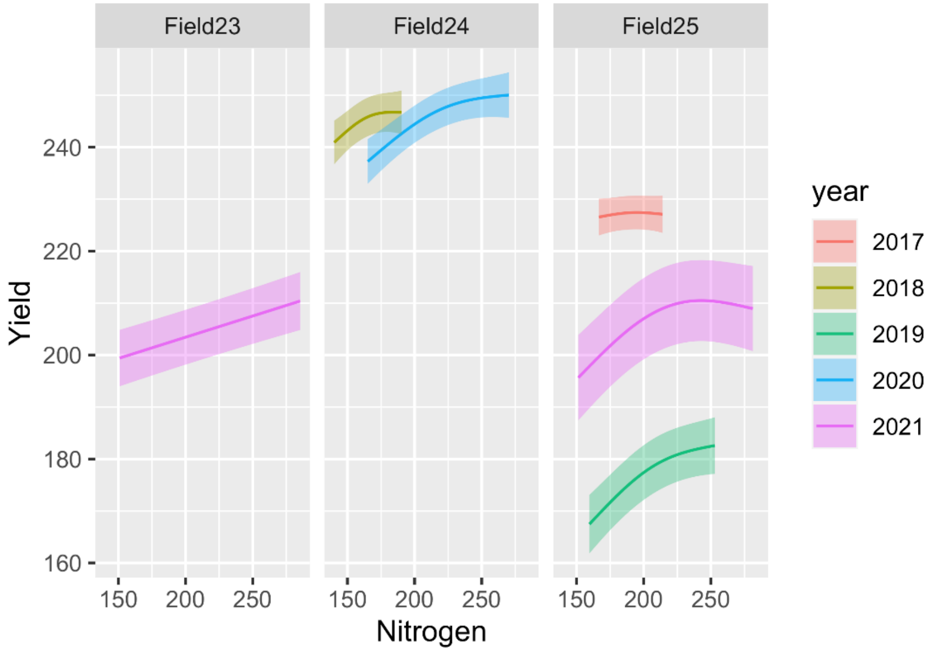

Figure 4: Estimated Yield Response to Nitrogen on Farm HO (GAM Model)

Conclusion

Including the economic perspective in their research on optimizing nitrogen application and the MRTN recommendation tool is a significant contribution for both academia and industry. However, the results of this study reveal that the MRTN recommendations are significantly riskier than advertised.

Tables 9.2 and 9.4 exemplify that yield level and weather conditions can vary significantly within the same MRTN designated region; consequently, the preferred nitrogen application rate on different fields within the same region is likely to vary by nature. The MRTN recommendation tool may not be applicable in the real world for the reason that it does not differentiate between fields that are hundreds of miles apart, with different soil compositions, and experiencing vastly different weather conditions.

In conclusion, adapting to the MRTN recommendations without conducting additional research on the soil conditions and yield performance from previous years on a field poses substantial economic risks due to both yield loss from insufficient nitrogen application and high application costs without a matching rise in yield.

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Appendix

The fact that only one model was used to estimate the production function $f(N)$ is a significant deficiency in the existing literature that reviews the MRTN recommendation tool, as the estimated optimal nitrogen rates can vary substantially depending on the model chosen. This study assesses the robustness of the GAM results by comparing the findings of three additional models. Specifically, the shape constrained additive model, the spatial error model with quadratic form, and the quadratic plateau model are employed for robustness testing.

Shape Constrained Additive Model (SCAM)

A shape constrained additive model (Pya and Wood, 2015) provides functions for generalized additive modelling under shape constraints on the component functions of the linear predictor of the GAM. Models can contain multiple shape constrained and unconstrained terms as well as bivariate smooths with double or single monotonicity. Univariate smooths under eight possible shape constraints such as monotonically increasing/decreasing, convex/concave, increasing/decreasing and convex, increasing/decreasing and concave, are available as model terms.

Spatial Error Model (SEM)

A quadratic yield response function form with a spatial error term (Bongiovanni et al., 2000; Bullock et al., 2002; Anselin et al., 2004) is:

$$Y = aN + bN^2 + c + u \tag{1}$$

Where the slope a and b describes the curvature of the yield response function, while c estimates the average yield without application of nitrogen.

Note that there are many other variables affecting yield that were left out of the yield response function above, which may result in a spatial correlation of the error term. Thus, a spatial error term is included in the residuals of the estimated yield response function to capture spatial correlation. The spatial simultaneous autoregressive error model is used to estimate the spatial error:

$$u = \lambda W u + e \tag{2}$$

where W is the spatial weighted matrix, λ is a spatial autoregressive coefficient, which is assumed to be 0.75, and e is a vector of the error term. A nearest neighborhood structure was used as the weighting matrix W.

Quadratic Plateau Model (QPM)

A quadratic plateau model (Neeteson and Wadman, 1987; Cerrato and Blackmer, 1990; Mallarino and Blackmer, 1992; Bullock and Bullock, 1994) is similar to a linear plateau model, except that the linear segment is replaced with a quadratic function.

The fitted parameters a, b, and clx designate the best fit intercept, linear coefficient, and critical x value. The quadratic coefficient is calculated as

$$-0.5^{*}b/clx \tag{3}$$

and the plateau value is denoted as

$$a + b^{*}clx - 0.5^{*}b^{*}clx \tag{4}$$

The results obtained from different models are summarized in Table 1, as shown below.

Table 1: Optimal nitrogen rates estimated by four different models

Farm	Field	Year	MRTN (lb/ac)[a]	GAM (lb/ac)[b]	SCAM (lb/ac)[c]	SEM (lb/ac)[d]	QPM (lb/ac)[e]	Grower Chosen Rate (lb/ac)[f]
Region: Central Illinois								
GI	Field1	2018	196 (178, 213)	176.8	172.2	176.8	175.3	180
	Field2	2017	182 (167, 197)	184.7	182.8	168.4	187.2	210
		2019	186 (171, 202)	188.9	191.9	190.4	184.4	235
OV	Field3	2017	182 (167, 197)	201.4	201.4	201.4	201.4	180
RO	Field4	2018	196 (178, 213)	231.1	231.1	231.1	NA	210
	Field5	2020	184 (170, 200)	226.8	226.8	226.8	NA	179.6
	Field6	2016	177 (164, 191)	217.7	217.7	217.7	217.7	198.5
SA	Field7	2016	177 (164, 191)	160	160	160	NA	200.3
		2018	196 (178, 213)	219	219	219	212.4	210
		2020	184 (170, 200)	219.5	221.5	225.6	222.5	210
	Field8	2017	182 (167, 197)	NA	NA	NA	NA	198.3
		2021	190 (175, 206)	208.8	204.3	220.2	240.6	200
Region: Northern Illinois								
GO	Field9	2019	178 (160, 195)	204.7	212.3	194.7	193.5	180
	Field10	2020	175 (159, 192)	128.5	128.5	236.8	218.2	186
LA	Field11	2020	175 (159, 192)	203	203	203	174	180
	Field12	2017	181 (155, 188)	212	212	212	212	192
	Field13	2018	188 (169, 207)	231.6	231.6	180.5	166.7	192
NE	Field14	2021	182 (165, 199)	118.2	NA	118.2	NA	181
	Field15	2017	181 (155, 188)	146.4	146.4	184.2	201	187.2
		2021	182 (165, 199)	118.6	121	173.5	136.9	181
	Field16	2020	175 (159, 192)	208.1	215.6	200.7	204.9	180.7
Region: Southern Illinois								
BO	Field17	2016	195 (183, 210)	177.6	187.3	169.1	NA	180
		2018	217 (198, 239)	NA	NA	NA	NA	180
		2020	204 (189, 220)	253.6	265.4	261.4	281.1	215

Farm	Field	Year	MRTN (lb/ac)[a]	GAM (lb/ac)[b]	SCAM (lb/ac)[c]	SEM (lb/ac)[d]	QPM (lb/ac)[e]	Grower Chosen Rate (lb/ac)[f]
	Field18	2016	195 (183, 210)	198.5	186.5	198.5	154.1	180
		2018	217 (198, 239)	NA	NA	NA	NA	198
		2020	204 (189, 220)	266.1	247.4	150.3	150.3	215
CA	Field19	2017	200 (186, 217)	236.9	236.9	236.9	236.9	160
		2019	206 (191, 224)	244.3	244.3	NA	244.3	210
	Field20	2019	206 (191, 224)	250	241.6	250	226.1	191.9
		2021	210 (194, 228)	NA	NA	NA	NA	180
WE	Field21	2017	200 (186, 217)	228.9	228.9	228.9	228.9	757.5
		2019	206 (191, 224)	268.4	261.7	268.4	268.4	863.4
		2021	210 (194, 228)	306	288.5	320.6	301.6	250
	Field22	2018	217 (198, 239)	178.7	172.9	169.8	175.2	180
Region: Ohio								
HO	Field23	2021	192 (175, 210)	150.9	150.9	150.9	150.9	(172.2,196.8)
	Field24	2018	200 (179, 219)	168.5	177.1	190.3	165.5	(75.7,95.6)
		2020	185 (168, 202)	230.9	230.9	270.2	244.7	(180.4,196.8)
	Field25	2017	180 (163, 198)	166.6	166.6	182.9	166.6	189.9
		2019	186 (169, 205)	224.7	236	253	246.4	(155.8,180.4)
		2021	192 (175, 210)	210.4	193.3	211.7	205.1	(155.8,180.4)
NI	Field26	2018	200 (179, 219)	242	242	242	242	180

Note: All four models' estimates of the optimal nitrogen rate will be NA when the MRTN rate is outside the trial's applied nitrogen rate range because the MRTN rate cannot be compared to the estimations in that situation.

[a]This column provides the MRTN rates obtained from the MRTN website, and the profitable range is presented below the MRTN rates.

[b]This column provides the optimal nitrogen rate estimated by the gam model.

[c]This column provides the optimal nitrogen rate estimated by the scam model. It indicates that the scam model dose not converge when it is NA.

[d]This column provides the optimal nitrogen rate estimated by the spatial error model.

[e]This column provides the optimal nitrogen rate estimated by the quadratic plateau model. It indicates that the there exists a singularity issue in the regression when it is NA.

[f]The grower chosen rates are shown in this column. When a commercial prescription map is available, a range is given, and when a farmer is adhering to a previous rate, a single rate is given. When the grower selected rates are significantly lower than in other fields and years, a base rate farmer would have been applied in advance, but we are unsure of what the base rate would have been.

Economics of strip intercropping with autonomous machines

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Abstract

Autonomous machines have the potential to radically change arable farming, ensure sustainable food production and build resilience of agro-ecosystems. Studies on autonomous arable farming have focused on Precision Agriculture (PA) in monocultures. One of the next steps is to consider the regenerative farming synergy of mixed cropping. Agro-ecology innovators have suggested many mixed cropping patterns (e.g., pixel, patch, strip cropping, and individual plant intercropping). Because of differences in plant height and growth pattern, automating mixed cropping is proving to be an engineering challenge. Strip cropping is technically the simplest mixed cropping system and technically feasible with conventional equipment. The agronomic benefits of strip cropping are well understood (e.g. higher yields, fewer pest problems), but the higher labour requirements have prevented widespread use in mechanized farming. Researchers have long hypothesized that autonomous machines might make strip cropping economically feasible. To test this hypothesis this study estimates field times (hr/ha), field efficiency (%) and economic feasibility with the Hands Free Hectare-Linear Programming (HFH-LP) model and associated algorithms. Because researchers in the US and Argentina have quantified strip cropping effects in maize and soybean systems, the study considers maize-soybean farms of 267 ha, 444 ha, 5330 ha and 10000 ha operated with conventional 38 hp, 250 hp and 310 hp tractors in the US Corn belt. Using swarm robot concepts and based on the HFH experience, the autonomous machine scenario uses 38 hp tractors and corresponding combine, both retrofitted for autonomy. The results of the long term 'steady state model' shows that swarm robotics reduce per unit production cost and increase profits compared to conventional monocrop systems. Profitable strip cropping with autonomous machines could restore and improve in-field biodiversity and ecosystem services through a sustainable techno-economic farming approach, and address the demand for healthier food while promoting environmental sustainability.

Keywords

Swarm robotics, regenerative agriculture, profitability, economies of size, economies of scope, linear programming.

Presenter Profile

Mr. A. K. M. Abdullah Al-Amin is an Elizabeth Creak Fellow working as a PhD researcher at Harper Adams University in the United Kingdom. He is on the staff of the Bangladesh Agricultural University, Mymensingh, Bangladesh as an Assistant Professor. In Bangladesh he was awarded the “University Prize” and “Prime Minister Gold Medal-2014” for his excellent academic performance at Bachelor level. He was awarded prestigious “Outstanding Graduate Student 2022” by the International Society of Precision Agriculture (ISPA). His research interests encompass the economics of agricultural technology, especially precision agriculture focused on autonomous crop machines, climate change adaptation, environmental impact assessment, and ecosystem services conservation.

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Evaluating the use of electrical conductivity for defining variable-rate management of nitrogen and seed for corn production

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Abstract

This paper uses data from thirty-three on-farm experiments to explore the use of electrical conductivity (EC) for defining seeding and nitrogen rates for corn production. We estimate the yield response to nitrogen and seeding rates, including an interaction term with EC for each of the trial years. We then determine the optimal uniform and variables rates and compare the profits. If EC can be used on different fields and years, then the correlation between EC and the optimal rates should be consistent across fields and years. We find that the optimal variables rates do not produce profits above $5 an acre for the majority of the fields. Additionally, in different years on the same field, the high EC areas may require more or less of the inputs. The inconsistency of the relationship between EC and the optimal rates does not enable EC to be accurately used for variable rate applications across different growing years. While EC will continue to be important in detecting salt affected soils and can be calibrated for detection of specific soil elements, the use of EC for variable-rate input management is not recommended.

Keywords

Variable rate, Electrical conductivity, On-farm experimentation

Presenter Profiles

Brittani Edge is a doctoral candidate at the University of Illinois Urbana-Champaign. Her work focuses on precision agriculture and on-farm experiments. Particularly, she is interested in the economic benefits to farmers who participate in the experiments and how researchers can further improve the benefits of this line of research.

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Introduction

Today precision agriculture technology (PAT) and variable-rate technology (VRT) are widely available, and many commercial algorithms or crop consultants will provide prescriptions to farmers. However, there is not sufficient evidence that the prescriptions are profitable (Sozzi et al 2021; Colaco and Bramley 2018). Consequently, producers do not have confidence in the quality of commercial prescriptions (Bullock et al. 2020; Gardner et al. 2021). The methodologies to produce these prescriptions are also trying to replace or reduce the need for expensive data collection, such as soil sampling, with remote sensing, yield potential, or electrical conductivity. The methods used to collect soil characteristics are labour intensive, resulting in high costs for producers. Thus, farmers collect this data every few years rather than annually and a scale of one sample per acre. Electrical conductivity (EC) is a more reasonably priced alternative to soil sampling, is measured on a finer scale, and is related to soil characteristics that describe soil texture and are known to affect nitrogen response, such as clay content and organic matter (Heege 2013).

EC measures the soil's ability to conduct electrical current measured in miliseimens per meter and can be used for a variety of purposes depending on the collection area and calibration. EC can locate permafrost, gravel deposits, pollution plumes in groundwater, pipes, and other features. The many uses of EC highlight the importance of knowing what EC is being used for in a specific area before data collection. In agronomy and soil science, EC is used to locate salt affected soils and for soil mapping (McNeill 1980). While there is an existing literature the relationship between EC and crop yield, it is not clear if and how EC can be used in crop management decisions. For EC to impact the optimal management, it must be shown that EC changes the marginal response of yield to seed or nitrogen applications. If a consistent relationship can be defined between the yield response to nitrogen or seed and EC, this would be an important contribution in the PA literature. Specifically, this knowledge benefits small farmers who are unable to conduct on-farm experiments or those who are deciding whether to invest in VR equipment.

This paper investigates: (1) the suitability of EC as a characteristic for VR management of seed and nitrogen application and (2) the relationship between EC and field characteristics such as soil type and topography. In order for EC to be a suitable characteristic for defining VR management, there are two criteria. First, the estimated VR economically optimal input rates (EOIR) from EC result in profit increases over the uniform EOIR. Second, the relationship between EC and the EONR can be consistently explained so that the results can be used on different fields.

We use data from 33 maize trials to estimate the yield response functions using a shape-constrained additive model (SCAM) with smoothing functions for the nitrogen and seed treatments and interaction terms between seed, nitrogen, and EC. For each field trial, we present the profits from VR application using EC and the relationship between the estimated optimal input rates (EOIR) and EC. The results from this research show that using EC to define VR management does not increase profits in most of the fields. Further, the relationship between EC and the EOIR is not consistent across the different fields. Therefore, for most fields, EC maps are not sufficient for defining VR management of seed or nitrogen. Additionally, future literature may want to move away from VR application on homogenous fields such as these. On fields with more variation in the soil and topology, EC may describe nitrogen or seed response where we are unable to capture it in this research.

Electrical Conductivity and Management Zones

There are two types of EC sensors used in the agronomic literature. Direct sensing is the older method which uses four or more electrodes that maintain contact with the soil. Originally, these sensors were made to be carried across the field; today, this is the method used by the Veris machine that can be driven across a field rather than carried. The second is the electromagnetic method which uses two coils, one sending and one receiving, to measure resistivity of the soil without contact; the sensor is a bar that needs to be made portable through a sled and vehicle for transportation. Figure 1 contains two pictures from Sudduth et al. (2003) depicting the two EC sensors being implemented in the field. This is the method employed by the EM38 machine. Early trials in the DIFM project used an EM38 measurement, and later trials used a Veris machine. Thus, it is important to understand differences between these measurement methods.

Figure 1 Comparison of the electromagnetic and contact-based EC sensors in the field. (Left) Electromagnetic Geonics EM38 sensor (Right) Veris 3100 contact EC sensor. Source: (Sudduth et al., 2003).

Sudduth et al. 2003 give an extended theoretical description and empirical comparison of the two EC sensors. Their analysis discusses the benefits of each of the sensors and also the differences between the EC reported. For example, the Veris sensor is not prone to interference from humidity and temperature and does not need to be calibrated at each use. However, on rocky soils, the Veris machine can lose contact with the soil, resulting in clear outliers in the measurements. Apparent electrical conductivity is a weighted average of the conductivity over the soil profiles reached by the sensors. The weights for the different soil depths are described in figure 2 from Sudduth et al. 2003. Intuitively, comparing the shallow and deep readings from the Veris machine shows that the deep reading is more responsive to deeper soils than the shallow reading. On the other hand, the EM38 vertical mode is more responsive to deeper soils than Veris shallow or deep readings. Consequently, while Sudduth et al. (2003) find that EC maps taken with different sensors are similar, the differences between the sensors are more apparent with more layered soils where variation in EC may be better measured by one sensor than another. But overall, the EC reading correlated well with the clay content and CEC from analysed soil samples on the four fields included in their research (Sudduth et al. 2003). The authors emphasize that choosing the right sensor will depend on the intended use and location.

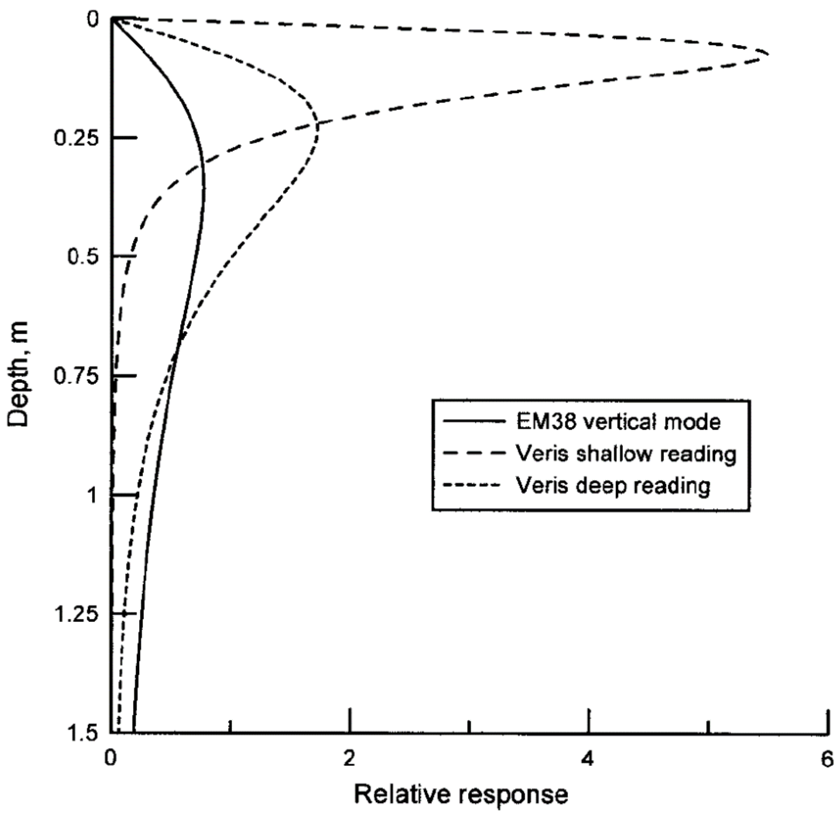

Figure 2 Response of electrical conductivity sensors as a function of soil depth Source: (Sudduth et al., 2003).

Literature on EC highlights the ambiguity of this measure; EC is correlated with clay, water, organic matter, salts, and the interactions between these variables (Heege 2013). While salt detection is not as likely in humid climates, the other variables play important roles, particularly clay and water (Heege 2013). EC and clay are highly correlated, and clay impacts yield response to nitrogen application through organic matter. Clay content and organic matter both increase yield potential; however, heavy rainfall may alter the nature of the relationship between EC and the marginal response to nitrogen. While increased organic matter can reduce the economically optimal nitrogen rate, heavy rainfall can also lead to nitrogen losses. The nitrogen losses will be higher in clay soils, which will likely have a higher EONR. These two scenarios make the relationship between EC harder to establish. As noted by Heege (2013), there is a level of clay content where the yields may decrease due to waterlogging or dense soil texture.

As expected, past research indicates both positive and negative relationships between the variable and yield (Kitchen et al. 2003; Kravchenko et al. 2003). Kravchenko et al. find that EC had a negative effect on yield when there was high March precipitation; this result is consistent with high EC values in Illinois being associated with high levels of clay, water content, and poor drainage. Soil type can also explain the relationship between EC and yield because soils contain different types of salts with different relationships to crop yield (King et al. 2005). Miao et al. (2018) compare using EC zones to soil zones for one field, finding EC zones perform better, but zones combining soil and EC perform best in terms of profits. Most recently, da Silva et al. conducted experiments on three fields in two years, finding EC and clay content to best describe yield response to seeing rate (2022). However, the derived seeding maps were designed to maximize yield rather than profits, and the second-year analysis was performed by applying the prescription, not a trial, to confirm the previous year results (da Silva et al. 2022).

This research contributes to a large literature on VR management of nitrogen and seeding rates and literature on the use of EC for VR management. Early work used soil tests to measure soil properties such as organic matter, phosphorous, and in-soil nitrogen (Carr et al. 1991; Ferguson et al. 1996; Mausbach et al. 1993). The cost of soil sampling is high due to the physical labor of taking the samples and the lab analysis; thus, early research tried to understand how much the sampling density could be reduced while maintaining profitable management zones. Ferguson et al. (2016) found low density soils maps could produce VR applications resulting resulted in higher profits than a single-rate application. (Ferguson et al. 1996). However, homogenous Midwest fields may not benefit from VR application of inputs as noted by Bullock et al. 1998 and Bullock et al. 2020.

Yield maps are a low-cost alternative to soil zones, and as stated previously, many researchers believe that yield potential is essential for determining EOIR. Unlike a soil map that may be used for a few years, one year of yield will not be representative due to weather fluctuations. Thus, research evaluating yield zones use multiple years of past yield data to delineate management zones (Ferguson et al. 1996; King et al. 2005; Hörbe et al. 2013;). The zones attempt to identify areas of the field with consistently high yield, low yield, or mixed yields. Some studies have shown profits from yield zones (Hörbe et al. 2013), but generally the relationship between yield level and EOIR appears to be weak (Bachmeir et al. 2009; Scharf et al. 2006). However, this has not dissuaded the use of yield zones or the evaluation of management zones by looking at their yield prediction. Beyond defining management zones, King identifies yield maps as a way to assess field variability and, thus, suitability for VR application (King et al. 2005). Rather than soil zones or yield zones, this paper focuses on EC; the collection of EC is cheaper than soil sampling and captures underlying soil properties and texture more directly than yield maps. The use of EC in zoning does not require multiple years of data, although it can help remove the variation due to weather.

There are several limitations and gaps in the existing literature. First, the previous literature on EC and management zones lacks economic evaluation. Many of the papers delineate management zones without assigning optimal input rates and evaluating the profits compared to an optimal uniform rate (Cillis et al. 2018; Colaco and Bramley 2018; Velasco 2020; Kayad 2021; da Silva et al. 2022). Much of the literature evaluates management zones based on yield prediction or profit comparison to the farmer’s chosen rate, which may be far from the optimal uniform rate. Given recent work by Bullock et al. (2020) which indicates that the largest profit gains from agronomic trials may be from a better estimation of the optimal uniform rate, these studies are likely overestimating the profitability of the management zones. Second, the papers evaluating the use of EC for nitrogen management have limited data, from one to four fields (Cillis et al. 2018; Miao 2018; da Silva et al. 2022). This paper is unique in its access to trial data from 33 different whole-field randomized trials where EC maps are available.

Data

These data come from thirty-three completely randomized seed and nitrogen trials from 2016 to 2021 with the Data Intensive Farm Management project at the University of Illinois in Urbana-Champaign. Most trials had four nitrogen rates and four seed rates for 16 treatments. The fields differ in the nitrogen types, including UAN32, UAN28, and urea. Some fields included a base application in the fall or a preplant application. The treatment rates for nitrogen and seed are designed around the farms' status quo rates for each field; thus, the rates are not centred around the same values in each trial, nor is the range of rates the same across fields.

The trial plot dimensions are also different across fields based on the farms' equipment size. The trial plot width ensures accurate application of inputs and collection of yield in each plot. Many of these farms have a 30-foot harvester and 60-foot applicators; thus, the most common plot width is 60 feet. Additionally, the plot length is designed for enough data after eliminating the observations around the transition zone from one plot to the next, where the yield monitor is likely to have errors as it moves across plots with different treatments and mean yields. The exact length needed for accurate yield is not known and depends on the field's yield response and the yield monitor used. This is a difficult area of research due to ongoing improvements in the technology, making old results inapplicable to new yield monitors. However, recent research by Gauci et al. (2022) suggests that at a length of 200 feet the yield monitor is able to identify a change in harvest level; however, they say that a length of 397 feet may be necessary if the yield monitor is not properly calibrated. The plot length for the trials was around 280 feet given the constraints mentioned.

The trial is designed assuming the operator will drive through the middle each plot, maintaining a steady speed. However, in practice, they will take breaks, slow down and speed up, and will likely veer from the centre of the plot. All of these events cause errors in the data reported and points where they occur are removed from the final datasets. The first step in data processing is removing the headlands and sidelands of each trial. When the trials are designed, plots on the edges of the field and partial plots are assigned the rate the farmer would normally use, and these plots are not included in the analysis. There are too few observations in small plots, and the driving patterns and sun or wind exposure on the edge of the field result in unreliable data. After removing the bordering plots on the field, the yield and as applied data are cleaned removing observations outside of three standard deviations from the mean.

Rather than using the original trial plots, the yield observations are the "building blocks" for the final units of observation, where they are aggregated into groups after going through a screening to identify treatment mixing. The general steps are as follows:

1. Polygonise the yield and treatment points and intersect all polygons
2. Calculate the area-weighted deviation from the mean of the treatment rates inside each yield polygon
3. Remove yield polygons with an area-weighted deviation greater than 40 pounds of nitrogen or 20 thousand seed per acre
4. Group the yield polygons sequentially, allowing a group to continue if the treatment does not change by an amount greater than 20 pounds of nitrogen or 10 thousand seed
5. Define subgroups for each group to reach a length of at least 30 feet
6. Define polygon around each subgroup and aggregate all data into this new unit of observation

Table 1 reports the soil and field characteristics of each field. Fields 1 and 2 have low yields for multiple trial years, with average yield as low as 138 and 148 bushels per acre. Field 14 has consistently high average yields, ranging from 220 to 254 bushels per acre. In general, the high yield fields tend to have low variation while the low yielding fields have high variation in yields.

The high variation in Fields 1 and 2 may be a result of distinct but generally poor growing conditions, driven by texture or rooting depth. On the other hand, Field 14 appears to have homogenously good growing conditions across the field. As is common in Central and Northern Illinois, these fields have low variation in elevation. This may lead to results similar to those found in the past literature indicating VR applications are not profitable for this field type (Bullock et al. 1998, Thrikwala et al. 1999, Isik et al. 2001). There are differences in the soil texture due to weathering, specifically Fields 2 and 9 are on highly weathered soils.

Table 1: Table of Field Characteristics

Field	*Year*	*Yield (bu/ac) (Mean/SD)*	*ECS (Mean/SD)*	*Elevation (Mean/SD)*	*N (lbs/ac) (Mean/SD)*	*S (k/ac) (Mean/SD)*	*EC Clay Correlation (Mean/SD)*
1	2016	138.11 36.52	28.06 7.53	175.03 0.35	180 0	33.3 4.06	0.16***
	2018	173.96 36.31	27.55 7.45	175.04 0.3	156.89 0	31.33 2.7	0.17***
	2020	143.6 40.35	27.66 7.48	175.08 0.31	185.92 0	27.63 6.23	0.21***
2	2016	128.97 34.12	31.65 6.7	175.37 0.17	198.47 0	33.18 4.06	-0.25***
	2018	205.27 25.12	32.32 8.34	175.18 0.36	170.98 0	31.15 2.6	-0.45***
	2020	143.81 39.21	31.94 7.86	175.33 0.24	193.18 0	26.47 6.26	-0.35***
3	2017	172.56 29.5	21.5 6.81	174.86 0.57	199.71 0	33.05 3.84	-0.1***
4	2018	249.61 9.15	45.17 7.22	204.44 0.41	200.94 0	32.45 2.79	-0.04*
5	2017	234.88 13.39	27.48 6.36	210.14 0.58	223.46 0	35.22 2.8	0.64***
	2019	206.78 11.12	27.2 6.53	688.49 2.52	236.55 0	32.69 5.4	0.69***
6	2017	233.4 14.22	10.69 5.07	309.03 1.15	199.76 0	34.06 2.29	0.52***
	2019	185.52 16.66	10.22 4.55	309.06 1.07	183.28 0	34.8 2.51	0.38***
	2021	213.84 22.61	10.42 4.85	309 1.05	194.39 0	33.14 5.91	0.17***
7	2017	345.36 25.31	11.35 6.19	265.72 0.86	194.87 0	34.5 3.33	0.15***
	2019	200.47 17.49	10.94 6.29	265.78 0.93	NA	35.38 3.78	0.2***
8	2018	239.96 29.57	37.94 8.8	NA	229.95 0	33.54 4.05	0.37***
	2021	220.97 26.62	37.92 8.49	NA	NA	35.5 5.3	0.39***
9	2017	261.99 20.91	27.1 7.52	205.53 4.17	209.91 0	33.66 2.55	0.44***
	2021	223.72 23.24	28.29 7.22	204.04 0.27	123.9 0	30.6 3.96	0.65***
10	2018	240.07 16.23	34.12 10.36	209.66 4.28	108.27 0	32.58 2.9	0.43***

	2020	222.49 21.32	34.43 10.8	209.8 4.46	187.22 0	26.64 4.38	0.5***
11	2017	229.17 11.89	82.73 6.3	233.3 0.85	153.13 0	33.88 2.59	0.12***
12	2018	217.35 30.17	48.88 6.5	204.25 0.7	209.23 0	36.2 0.09	-0.66***
13	2016	228.91 12.67	27.05 5.98	205.81 0.53	198.45 0	34.33 3.79	0.24***
14	2016	220.5 16.73	31.59 8.39	193.43 0.75	160 0	33.95 4.13	-0.03
	2018	254.42 19.49	31.42 8.46	193.48 0.78	209.89 0	32.82 2.46	-0.06***
	2020	244.96 11.32	23.69 9.12	194.19 0.62	188.19 0	32.55 6.11	-0.34***
15	2017	224.67 13.69	54.18 9.6	192.23 0.61	252.97 0	33.74 3.23	-0.39***
	2021	237.54 25.72	54.44 10.34	192.25 0.83	139.81 0	33.04 5.25	-0.05***
16	2017	230.3 15.09	29.36 5.75	191.48 0.38	218.31 0	32.19 3.5	0.04
	2019	205.29 28.91	28.93 5.33	191.47 0.41	237.58 0	33.31 4.14	0.06**
17	2018	235.77 21.96	31.12 8.32	191.37 0.6	160.37 0	32.36 3.72	0.04

Because EC is not a direct measure of a particular soil property, the literature has emphasized the importance of understanding what EC is capturing on a field before defining a management strategy. Past research focused on this question of what soil characteristics are being captured by EC, finding clay, CEC, and Ca to be common elements associated with high EC measurements (King et al. 2005). The fields in this research do not have soil testing; thus, the SSURGO database is utilized to look at EC measurements within the different soil types and characteristics such as the drainage class. Box plots compare the EC data in each of the map units and drainage classes. For most fields, the poorly drained areas of the fields had higher EC values than well-drained or moderately drained soils. This result follows from the fact that EC increases with soil moisture and clay content. If EC is a profitable investment, it should provide more information than the publicly available SSURGO maps; thus, the fields where the SSURGO information does not explain EC are of particular interest.

Weather data is collected from the Daymet database by ORNL, and key weather measures are calculated for each field trial. Past research highlights the importance of weather not just impacting yield but also the nitrogen dynamics on the field that influence the yield response to nitrogen (Bean et al 2021; King et al. 2005; Tremblay et al 2012). We calculate measures over the whole growing season and during critical periods in the maize development. The estimated growing degree days to pollination and maturity (black layer) is often found on the breeders' websites. Combining this information with the hybrid, planting date, and daily weather data from DaymetR, we estimate the date of pollination and maturity for each trial. Then, we calculate the precipitation and temperature during a two-week period around pollination and the grain fill period from pollination until maturity. Thus, we can examine how weather around the critical growth stages impacts the potential use of EC for VR management. An additional weather measure used in the literature is the Shannon Diversity Index (SDI); the index was intended for use in species diversity across locations (Bronikowski and Webb 1996). However, several papers have adapted this measure to capture the evenness of the rainfall distribution throughout a growing season (Bean et al. 2021; Bronikowski and Webb 1996; Tremblay et al. 2012). The calculation of SDI is in equation 1 where $Rain_i$ is the rainfall on day i and N is the number of days in the calculation period.

$$SDI = \left(- \sum_{i}^{N} \frac{Rain_i}{\sum Rain_i} * \ln\left(\frac{Rain_i}{\sum Rain_i}\right) \right) \Big/ \ln(N) \quad (1)$$

The SDI calculations range between 0 (completely uneven) and 1 (completely even). When the rainfall is perfectly even across the days, SDI = 1; when all rainfall occurs on one day, SDI = 0.

Table 2 reports the rainfall and temperature measures during the growing season and critical growth stages. However, we present the total season precipitation, precipitation during pollination, precipitation during gran fill, SDI, temperature during pollination, and temperature during grain fill. Eight of the fields received less than the 45 centimetres of rain in the growing season, which is ideal for the region. Fields 1 and 2 had less than an inch of rainfall during pollination combined with an average temperature of 78, resulting in an increased variation in the yields for the 2020 trial year.

Table 2: Trial Weather Data for the Season and Critical Growth Stages

Field	Year	Prec Poll (in.)	Prec GF (in.)	SDI	Season Prec (in.)	Temp Poll (F)	Temp GF (F)
1	2016	4.88	12.34	0.72	22.11	74.94	77.88
	2018	3.51	8.91	0.68	19.10	77.61	76.57
	2020	0.40	11.49	0.68	19.41	78.80	75.36
2	2016	4.88	12.34	0.72	22.11	74.94	77.88
	2018	3.51	8.91	0.68	19.10	77.61	76.57
	2020	0.40	11.49	0.68	19.41	78.80	75.36
3	2017	0.75	4.86	0.63	16.22	78.33	74.49
4	2018	1.42	6.75	0.67	14.10	77.06	74.48
5	2017	2.88	4.46	0.66	18.95	77.04	71.19
	2019	0.34	6.68	0.69	19.42	78.37	73.56
6	2017	4.53	5.34	0.72	22.89	74.59	68.89
	2019	2.19	5.02	0.70	17.37	75.55	70.89
	2021	5.58	9.58	0.74	22.59	73.97	73.07
7	2017	6.25	8.61	0.67	21.26	71.51	66.92
	2019	1.70	16.84	0.76	33.58	75.78	67.46
8	2018	1.10	8.02	0.68	23.70	73.03	71.10
	2021	1.78	3.84	0.66	13.75	69.73	72.00
9	2017	3.51	3.03	0.61	12.63	74.31	67.99
	2021	3.71	5.86	0.69	22.51	71.63	73.70
10	2018	0.72	7.09	0.69	16.46	75.74	73.65
	2020	1.10	4.64	0.70	23.35	78.50	74.30
11	2017	1.39	5.40	0.66	22.36	75.17	73.55
12	2018	1.72	7.46	0.69	19.03	76.55	74.00
13	2016	5.10	10.04	0.72	22.07	74.68	75.38
14	2016	4.50	10.69	0.70	21.36	76.83	76.19
	2018	1.62	5.23	0.67	15.08	76.64	74.39
	2020	2.25	3.57	0.60	9.18	74.81	70.40
15	2017	2.19	4.03	0.66	11.50	76.75	70.51
	2021	3.26	5.75	0.72	18.70	72.72	74.43

Field	Year	Prec Poll (in.)	Prec GF (in.)	SDI	Season Prec (in.)	Temp Poll (F)	Temp GF (F)
16	2017	1.74	4.50	0.62	22.03	77.67	73.04
	2019	0.88	9.75	0.69	24.23	79.29	74.40
17	2018	2.15	11.14	0.66	21.57	77.48	75.95

Methods

We estimate the yield response to nitrogen and seeding rate, including an interaction with EC for both inputs. There is existing literature examining potential functional forms of yield's response to inputs. Popular forms include quadratic, quadratic plateau, linear plateau, von Leibig, and the Misterlich-Baule form. The last three are nonlinear forms that allow for non-substitutability between inputs, consistent with Leibig's Law of the Minimum (Llewelyn and Featherstone 1997). Studies comparing functional forms have consistently found that the quadratic form overestimates the maximum yield, resulting in over-estimating economically optimal nitrogen rates (Llewelyn and Featherstone 1997).

Another estimation method used in the ecology literature for predicting yield is GAM (Chen, O'Leary, and Evans 2019; Estes et al. 2013; Yee and Mitchell 1991). GAM allows flexibility in the estimated yield response and less sensitivity to outliers by introducing smoothing functions. One way of thinking about the model is that it is "data driven rather than model driven"; there is no need to specify the model before estimation (Yee and Mitchell 1991). Rather than a symmetric quadratic yield response curve, GAM can estimate a quadratic plateau if the data indicate such a response. More recently, Pya and Wood (2014) proposed a shape-constrained additive model (SCAM) that allows constraints such as concavity or monotonicity on the smoothing functions; they show that SCAM results in more efficient estimations than the more flexible GAM (Gardner et al. 2021). Here we use a SCAM estimation with zone i specific smoothing functions for seed and nitrogen rates and linear functions for field characteristics. The nitrogen function is constrained to be concave and monotonically increasing while the seed function is concave but can decrease if the seeding rate is too high. Equations (2) to (4) describe this process. First, yield is estimated as a function of nitrogen (N), seed (S), and other characteristics in the field (denoted by the vector X_C), such as topography variables.

$$y = \beta_0 + s_N(N) + s_S(S) + \beta_{ec}ec + \beta_{ecN}Nec + \beta_{ecS}Sec + \beta_{SN}SN \quad (2)$$

We estimate the optimal uniform input rate ($\widehat{EOIR}$), and optimal variable input rate ($\widehat{EONR}_i$), with subscript *VR*, and compare the profits in equations 2 and 3.

$$\pi_{VR} = \max_{(n,s)} yield(n,s,ec) - \boldsymbol{p}(n,s) \; for\ each\ observation\ j \; (3)$$

$$\pi_{UR} = \max_{(n,s)} \sum_{i}^{N} yield_{i,j}(n,s,ec) - \boldsymbol{p}(n,s) \; (4)$$

Where $\boldsymbol{p}$ is the price vector, and *j* is the observation. If $\pi_{VR} > \pi_{UR}$, then the variable rate application produces additional value beyond improving the uniform management rates. Further, if there is a consistent relationship between $\widehat{EONR}$ and EC, then we should see clear differences in the change in $\widehat{EONR}_i$ between high EC and low EC zones, and any outliers should be explained by weather or observable soil characteristics. For robustness, we also include results from an estimation with a spatial error model with a quadratic functional form.

Results

Table 3 presents the results of the yield estimation for each field. The results include the estimated uniform rate, the range of estimated optimal variable rates, the correlation between EC and the optimal seed and nitrogen rates, and the estimated profit difference between VR and UR application. The profit differences are below $5 per acre for all but two of the thirty-three fields analysed. Thus, the profit differences do not cover the cost of EC collection on the majority of fields. For field 8 which has the highest profit difference of $28 per acre, EC does not appear to be related to the soil types or the drainage class as seen in the box plots, and the correlation between EC and clay content from SSURGO is 0.37. A better understanding of what soil characteristics EC is correlated with on this field is necessary for the use of EC; note that the next year VR from EC does not induce additional profits. Similarly, field 6 has modest profits of $5.89 and $3.71 in two years but no VR estimates or profits in the last trial year.

Twenty-two trials have VR seeding although some of ranges are very narrow; thirteen fields indicate that low EC areas should receive lower seeding rates. Eighteen trials have VR nitrogen, with fifteen of those trial indicating high EC areas should receive higher nitrogen rates. The relationship between EC and seeding rate appears to be less consistent, changing across fields and between years in a single field. The three trials with a negative relationship between VR N and EC are not easily explained by field characteristics or weather; fields 1 and 2 are adjacent with similar soil and weather. Field 1 has a negative relationship between VR N for two trial years while field 2 displays a positive relationship for two trial years. Field 10 received very low rainfall during pollination and also shows a negative relationship between EC and N. The boxplots of EC and soil characteristics for this field show that EC increases in poorly drained fields and decreases in the eroded areas of the field. Combining the profit results and the consistency of the estimated relationship between EC and VR application, there is not an indication that a general management strategy could be defined from an EC map.

Table 3 Estimation Results from Analysis with EC Interaction with Seed and Nitrogen

Field	Year	UR	VR S	VR N	S Corr.	N Corr.	Profit ($/ac)
1	2016	27, 192	27 - 39	140 - 196	(+)	(-)	1.49
	2018	36, 197	30 - 36	NA	(-)		0.86
	2020	17, 288	NA	194 - 288		(-)	1.61
2	2016	39, 185	NA	181 - 197		(+)	0.06
	2018	36, 199	27 - 36	151 - 199	(-)	(+)	0.45
	2020	39, 264	NA	NA			0.00
3	2017	27, 236	NA	NA			0.00
4	2018	35, 163	35 - 37	149 - 225	(+)	(+)	0.92
5	2017	31, 202	31 - 39	168 - 230	(-)	(+)	0.50
	2019	33, 196	33 - 34	160 - 238	(-)	(+)	1.50
6	2017	30, 167	30 - 38	167 - 213	(+)	(+)	5.89
	2019	30, 218	30 - 39	210 - 252	(+)	(+)	3.71
	2021	42, 281	NA	NA			0.00
7	2017	34, 211	32 - 38	NA	(-)		0.51
	2019	35	34 - 36		(-)		0.02
8	2018	32, 167	32 - 34	167 - 231	(+)	(+)	28.79
	2021	27	NA				0.00

Field	Year	UR	VR S	VR N	S Corr.	N Corr.	Profit ($/ac)
9	2017	29, 146	NA	146 - 212		(+)	0.40
	2021	25, 237	MA	183 - 239		(+)	1.22
10	2018	33, 114	32 - 33	110 - 152	(-)	(-)	0.31
	2020	29, 231	27 - 35	NA	(+)		0.78
11	2017	33, 200	32 - 35	NA	(+)		0.74
12	2018	36, 231	NA	193 - 231		(+)	1.57
13	2016	31, 216	30 - 32	160 - 216	(-)	(+)	0.35
14	2016	28, 160	NA	160 - 220		(+)	0.00
	2018	36, 219	28 - 36	NA	(+)		0.04
	2020	29, 257	28 - 29	193 - 257	(-)	(+)	1.83
15	2017	29, 218	29 - 31	NA	(-)		0.01
	2021	30, 216	29 - 32	214 - 218	(-)	(+)	0.09
16	2017	37, 228	31 - 37	NA	(-)		0.03
	2019	38, 267	37 - 38	NA	(+)		0.01
17	2018	35, 174	34 - 35	NA	(-)		0.06

Conclusion

This research highlights the difficulty when using a measure like EC that is a proxy for many unobservable soil characteristics. While data collection may be profitable in some areas with distinct growing conditions, this is not true for the majority of fields presented here. Further, the relationship between EC and the optimal variable rates is not easily established for use across fields or years. This is a challenge faced in the management zone literature and may explain the prevalence of papers that establish management zones without defining seed or nitrogen prescriptions on the zones. EC is an important tool for mapping and detecting a variety of soil conditions for use in agriculture and other industries, but we do not find it to be promising for broad use in VRA.

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A Methodology to Investigate Challenges for Digital Twin Technology in Smart Agriculture

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Abstract

The agriculture sector is fundamental for social, economic, and environmental development. It needs novel approaches and technology-integrated processes to preserve its critical importance and survive for the future. Agricultural digitalization is an essential component of agricultural industrialization, focusing on agricultural research, infrastructural improvements, and data services. The combination of the Internet of Things/Everything (IoT/IoE) with RFID, sensors, and high-tech meters makes up smart agriculture (SA). Controlling and monitoring have become more easily applicable thanks to these technological improvements. SA replaces conventional farming methods with effective, rapid, and sustainable ones. It has the power to control water, pesticides, security, the environment, machines, and vehicles. Digital Twin (DT) technology is the mutual use of digital technologies such as remote sensing, IoT, and simulation. With its integrated structure, DT can help farmers to create a virtual twin of their physical entities in the virtual space. Accordingly, generating strategies and planning the production can be controlled by running simulations with the field's collected data. Therefore, this paper aims to investigate challenges to DT adoption in SA. For that purpose, a multi-criteria decision-making (MCDM) approach is suggested. DEMATEL technique is provided to prioritize and evaluate causal relationships for DT adoption challenges. The DEMATEL technique is integrated with the 2-Tuple Linguistic (2-TL) model to improve its ability to deal with linguistic variables and create a decision-making process closer to human cognitive processes. A real case study is provided to test the applicability of the suggested methodology, and further discussions are presented.

Keywords

2-Tuple Linguistic model, DEMATEL, Digital Twin, MCDM, Smart Agriculture

Presenter Profile

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Introduction

The agriculture sector is fundamental for social, economic, and environmental development. It needs novel approaches and technology-integrated processes to preserve its critical importance and survive for the future. We are talking about the new industrial revolution called Industry 4.0. Integrating Industry 4.0 technologies into various sectors showed tremendous benefits for sustainability (Lezoche et al., 2020). Fluctuating market conditions in a globally connected world challenge companies to continuously adapt and embrace digital transformation across all functions, including procurement, logistics, manufacturing, asset management, and factory operations (Bai et al., 2020).

Agriculture is one of the most crucial areas for humanity, with an importance that constantly increases with the depletion of natural resources. Agricultural digitalization is a critical component of agricultural industrialization, focusing on agricultural research, infrastructural improvements, and data services. The combination of the Internet of Things/Everything (IoT/IoE) with RFID, sensors, and high-tech meters makes up smart agriculture (SA). SA is the replacement of conventional farming methods with effective, rapid, and sustainable ones. It has the power to control water, pesticides, security, the environment, machines, and vehicles. In the short term, it proposes an end-to-end management and monitoring aspect of the entire system (De Clercq et al., 2018). Controlling and monitoring have become more easily applicable thanks to these technological improvements.

Thus, considering the significant improvements obtained by SA and technological transformation, this paper aims to investigate the main challenges for Digital Twin (DT) technology adoption in SA. DT technology is selected thanks to its disruptive effects on SA. The DT technology is the mutual use of digital technologies such as remote sensing, IoT, and simulation. With its integrated structure, DT can help farmers to create a virtual twin of their physical entities in the virtual space. Accordingly, generating strategies and planning the production can be controlled by running some simulations with the collected data from the field.

It is important to examine and thoroughly understand these technologies to get the highest efficiency from technology transfer and to use possible technologies in appropriate areas. Hence, this paper suggests a multi-criteria decision-making (MCDM) methodology to investigate challenges for DT technology in SA. The MCDM methodology is chosen to better understand the DT and SA area. For that purpose, 2-Tuple Linguistic (2-TL) (Herrera and Martínez, 2000) model-based methodology is proposed. The use of the 2-TL model allows operating with linguistic data. Operations with linguistic data both enable a deeper evaluation of the subject and prevent the accuracy of calculations from decreasing. The major contributions of this paper can be summarized as follows:

- Definition of main challenges for DT adoption in SA with a hierarchical structure.
- Evaluation of causal relationships for DT challenges for SA.
- Using the 2-TL model to generate a better understanding of DT technology and its use in SA.

The paper's organization is as follows: Next section will present the literature review. Then the methods are explained with the suggested MCDM model. Afterward, a case study is presented with detailed results and discussions. Finally, conclusions are provided at the end.

Literature Review

This section examines the academic and industrial literature to extract the main challenges for DT technology in SA. First, a search for “digital twin” and “smart agriculture” or “smart farming” keywords are searched in the Web of Science database, and the following keyword co-occurrence map is obtained as in Figure 1.

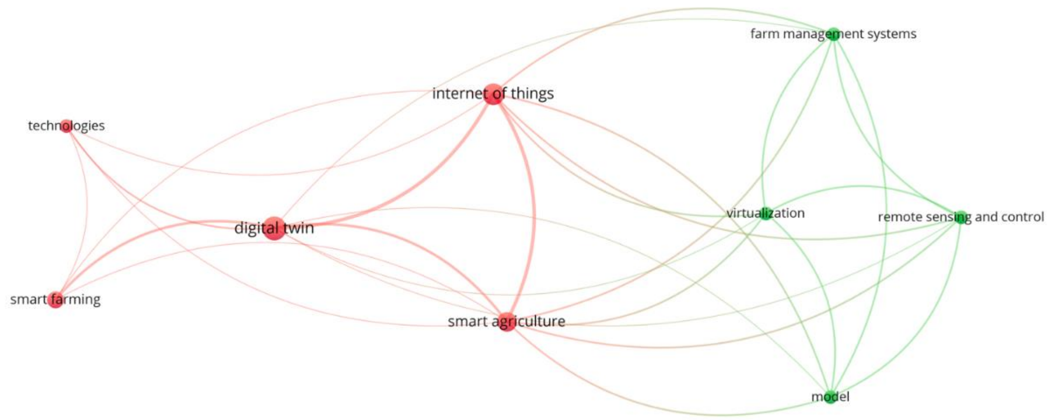

Figure 1 – Map visualization of keyword co-occurrences.

As seen in Figure 1, the internet of things (IoT) technology is highly emphasized in the DT literature (Haseeb et al., 2020; Ivanov and Dolgui, 2021; Nasirahmadi and Hensel, 2022). It is possible to assume IoT is one of the key enabler technologies for DT. Furthermore, remote sensing technologies are also highly concentrated in the literature. Remote sensing technologies are also seen as a key component in obtaining the data for virtualization.

Virtualization is another emphasized area in DT and SA subjects (Malik et al., 2020; Verdouw et al., 2021). The data flow provided by IoT and remote sensing technologies is used to virtualize the farm and its components to create *digital twins* in the digital world. Therefore, it stands linked to IoT, remote sensing, and farm management systems; it is crucial for efficient DT application. Accordingly, a farm with similar properties can be created in the virtual environment, and the system can be tested with simulations.

Considering the virtualization’s importance, “Data” is becoming essential for DT applications (Ivanov et al., 2019). On the other hand, a system to analyse this obtained data is indispensable. Accordingly, the “System” component can also be counted as a major necessity for efficient DT applications.

DT technology is a major technology for value creation, optimization, and agriculture supply chains (Denis et al., 2020). Hence, the stakeholders or system users also play an important role in DT technology’s efficient implications. The importance of collaboration of system components such as supply chain stakeholders is highly stated in the related literature (A. Parrott and L. Warshaw, 2017).

DT and SA literature covers the main barriers, challenges, and enablers for technological applications. Yet, none of the studies suggested a comprehensive review and assessment methodology for investigating challenges or enablers. Consequently, this paper offers an MCDM-based methodology to explore DT technology challenges in SA. MCDM methodology is selected thanks to its multi-criteria nature to create a deeper understanding of DT technology’s use and benefits (El Alaoui et al., 2019). The following section will detail the suggested model to investigate DT technology challenges.

Methods

The literature review process is essential for the suggested methodology. The model components (challenges from DT) are gathered from literature and examined with expert opinion. Figure 2 presents the proposed model to investigate DT challenges in SA.

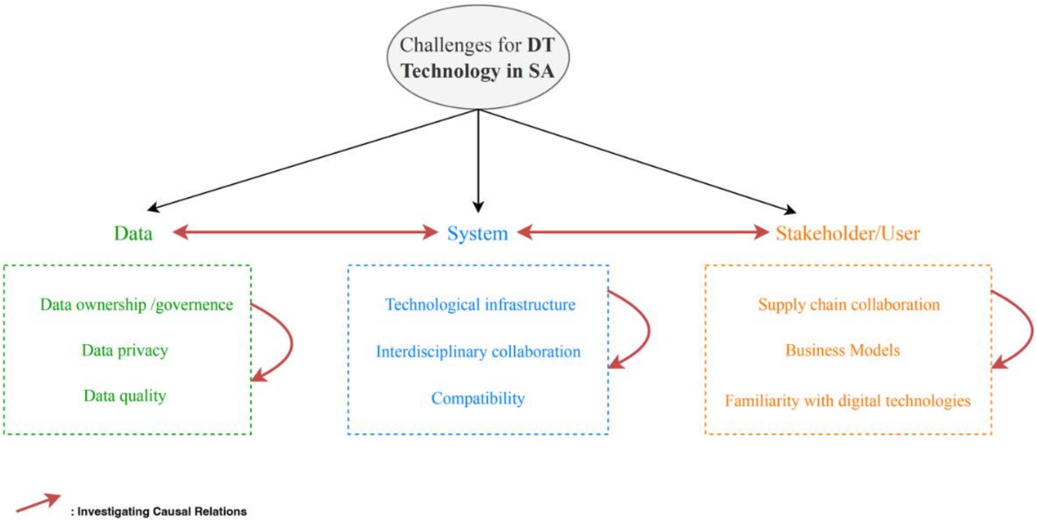

Figure 2 – The suggested model for investigating challenges for DT in SA (A. Parrott and L. Warshaw, 2017; Alves et al., 2019; Ivanov and Dolgui, 2021; Nasirahmadi and Hensel, 2022; Verdouw et al., 2021).

For that purpose, three main dimensions/criteria are detected from the literature, and followingly, their sub-criteria are defined as well with the same process. The 2-TL-DEMATEL methodology is recommended for causal relationship investigation and criteria prioritization. As the arrows in Figure 2 show, the causal relationships are also aimed to be examined in this model. The 2-TL-DEMATEL method is offered thanks to its ability to calculate these relationships. Moreover, instead of the conventional DEMATEL method, its integration with the 2-TL model is preferred to create a deeper understanding of DT technology and its application in SA. Because the 2-TL model allows dealing with linguistic variables, calculations and analysis become closer to the human cognitive processes. This section will present the suggested methods' details.

2-TL Linguistic Model

The 2-TL linguistic approach is first unveiled by (Herrera and Martínez, 2000). This model helps to work with heterogeneous information. Besides, it can handle multi-granular information. It is suitable for Group Decision Making (GDM), where group members have different experiences about the same subject. The 2-TL linguistic model is generally used with various MCDM models to emphasize their ability to deal with linguistic data and diminish data loss during the translation phase (Büyüközkan and Uztürk, 2022; Büyüközkan and Uztürk, 2017; Faizi et al., 2018).

The 2-TL fuzzy linguistic representation model represents the linguistic information using a 2-TL (S, α) here; S is a linguistic label, and α is a numerical value representing the value of the symbolic translation. The function is defined as:

$$\Delta_s : [0, g] \rightarrow \bar{S}$$

$$\Delta_s(\beta) = (S_i, \alpha), \text{with} \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases}$$

The linguistic term set *S* could be converted into 2-TL form by adding zero value as in the following relation:

$$S_i \in S \Rightarrow (S_i, 0)$$

The 2-TL linguistic model, a linguistic, symbolic computational model, modifies the fuzzy linguistic approach by including a parameter to the linguistic representation to increase the accuracy and the interpretability of the results (Martínez et al., 2015). The 2-TL linguistic model enables us to deal with variables closer to the human beings' cognitive processes and augment the computations' accuracy. For further details about the 2-TL model, readers can refer to (Martínez et al., 2015).

Group Decision Making

MCDM aims to discover the most appropriate alternative by conceiving multiple criteria concurrently. GDM may be adequate to reach an objective solution in this procedure. GDM involves various DMs having different backgrounds or points of view and handling the decision process distinctive from others. However, each decision-maker (DM) has shared awareness of cooperating with each other to achieve a collective decision. While having haziness and uncertainty, reaching a consensus for a decision in a group with different opinions turns out to be more critical. Generally, GDM problems are solved using classic approaches, such as the majority rule, minority rule, or total agreement. Yet, these techniques do not assure an acceptable solution for all DMs (Büyüközkan and Güleryüz, 2015)

In this paper, a consensus-reaching process is followed by the Delphi approach. Delphi is a communication instrument that facilitates group decision-making. The Delphi process is very efficient for supporting a group of individuals to handle complicated problems as a group. The method is based on expert knowledge, and the group is principally formed with knowledgeable and expert contributors (Büyüközkan et al., 2004).

The assessment made by DMs depends on their judgment and is subjective. Accordingly, instead of crisp numbers, the linguistic variables are given to the DMs to represent their data's uncertain and subjective nature.

2-TL DEMATEL Technique for DT Challenge Investigation

The DEMATEL technique can convert the interrelations between factors into an intelligible structural model of the system and divide the interrelations into cause-and-effect groups. Hence, it is an appropriate and valuable tool to analyse and rank the interdependent relationships among factors in a complex system for long-term strategic decision-making and indication of improvement scopes. The formulating steps of the 2-TL integrated DEMATEL method can be summarized as follows (Quader et al., 2016):

Step 1. Constructing the average matrix (*A*).

In this step, DMs give their evaluations,(S_{ij}, α_{ij}). They evaluate the direct effect between criteria *i* and *j*

Step 2. Calculating the initial direct influence matrix (*D*).

In this step, the matrix D is obtained by normalizing the matrix A with the following relation:

$$D = s.A$$
$$s = min\left[\frac{1}{max_{1\le i\le n}\sum_{j=1}^{n}\left|\Delta^{-1}(S_{ij},\alpha_{ij}).\right|},\frac{1}{max_{1\le j\le n}\sum_{i=1}^{n}\left|\Delta^{-1}(S_{ij},\alpha_{ij}).\right|}\right] \tag{3}$$

Step 3. Calculating the total direct/indirect influence matrix (*T*).

The total direct/indirect influence matrix is defined as the following relation:

$$T = D(I-D)^{-1} \tag{4}$$
$$T = \left[\Delta^{-1}(S_{ij},t_{ij})\right] i,j = 1,2 \dots n$$

In this relation, *I* is the identity matrix. In the *T* matrix, *d* and *r* values can be derived to determine the direct/indirect relationships between criteria. *d* refers to the dispatcher, and *r* indicates the receiver. These values can be obtained by using the following relation:

$$d = d_{n\times 1} = \left[\sum_{j=1}^{n}\Delta^{-1}(S_{ij},t_{ij})\right]_{n\times 1}$$
$$r = r_{n\times 1} = \left[\sum_{i=1}^{n}\Delta^{-1}(S_{ij},t_{ij})\right]_{1\times n} \tag{5}$$

r_i gives the summation of criterion's direct and indirect effects on the others. If c_i is the sum of the *jth* column of the matrix *T*, it refers to the sum of the direct and indirect effects that the criterion receives from others. In addition, when *j=i,,* $(d_i + r_i)$ gives an index of the strength of influences given and received, it refers to the degree of importance of criterion *i* in the problem. Also, if $(d_i\text{-}r_i)<0$, then criterion *i* is being affected by other criteria (Tzeng *et al.*, 2007). Moreover, if $(d_i\text{-}r_i)>0$, it means that the degree of affecting others is stronger than the degree of being affected.

Step 4. Analysing the cause-and-effect diagrams.

In this step, influence diagrams are obtained to investigate the cause-effect relations between main dimensions and sub-criteria. The Results and Discussion section will present comprehensive details of the recommended methodology for DT technology's challenges investigation.

Case Study

In this section, a real case study is applied to test the plausibility of the suggested methodology. For that purpose, a decision-making group of three experts is formed. What we expect from the experts is first to determine the relations between criteria.

Different sets are offered mainly to make DMs comfortable during their assessments and provide them a flexible environment to express their opinions about the subjects. The three experts have diverse backgrounds in digital technologies and SA. Accordingly, two different linguistic sets are provided to them for their assessments. Here Table 1 gives the details of linguistic sets.

Table 1: Linguistic sets provided to DMs.

2-TL sets	
$\boldsymbol{S^5}$	*None (N)-Low(L)- Medium (M)- High(H)-Perfect(P)*
$\boldsymbol{S^9}$	*None (N)-Low (L)-Medium Low (ML)-Almost Medium (AM)- Medium (M)-Almost High (AH)-High(H)- Very High (VH)-Perfect(P)*

The assessments for pairwise comparisons are obtained from the decision-making group. We have worked with three experts; two of them are highly experienced in digital technologies and the SA area. The third expert is only experienced in digital technologies and is less experienced in SA. Accordingly, we have provided $\boldsymbol{S^9}$ for two experts more experienced in SA and $\boldsymbol{S^5}$ *for* the third. Table 2 provides the linguistic assessments of the main criteria as an example, and followingly, Table 3 presents the aggregated average matrix.

Table 2: Expert assessments for main criteria.

DM1	**0.40**		
	Data	System	Stakeholder/User
Data	0.00	(VH,0)	(L,0)
System	(ML,0)	0.00	(AM,0)
Stakeholder/User	(AM,0)	(AH,0)	0.00
DM2	**0.40**		
	Data	System	Stakeholder/User
Data	0.00	(P,0)	(ML,0)
System	(ML,0)	0.00	(M,0)
Stakeholder/User	(AM,0)	(VH,0)	0.00
DM3	**0.20**		
	Data	System	Stakeholder/User
Data	0.00	(P,0)	(L,0)
System	(L,0)	0.00	(M,0)
Stakeholder/User	(H,0)	(H,0)	0.00

Table 3: Aggregated average matrix of 2-TL-DEMATEL.

	Data	**System**	**Stakeholder/User**
Data	0.00	(AM, -0.47)	(L, -0.47)
System	(L, -0.33)	0.00	(L, 0.20)
Stakeholder/User	(L, 0.20)	(ML, 0)	0.00

Having the aggregated average matrix allows following 2-TL- DEMATEL steps. Accordingly, the first step mentioned in the previous section is completed. As a result of the second step, a normalized average matrix is obtained by using Eq. (3). The normalized matrix is used to obtain the influence matrix by Eq. (4), and finally, the prioritization of criteria and causal relationships by using Eq. (5).

Table 4 shows the ranking and importance calculated by 2-TL-DEMATEL. Further discussions will be provided in the next section.

Table 4: Results of the 2-TL-DEMATEL methodology for DT challenge investigation in SA.

Main Challenges	Imp.	C/E	Sub-challenges	Imp.	C/E	O.I	N.O.I	Rank
Data	0.30	Cause	Data ownership/governance	**0.36**	Effect	0.11	0.11	6
			Data privacy	**0.32**	Cause	0.10	0.10	8
			Data quality	**0.32**	Effect	0.10	0.10	7
System	0.39	Effect	Technological infrastructure	**0.35**	Cause	0.14	0.13	1
			Interdisciplinary collaboration	**0.32**	Effect	0.13	0.12	3
			Compatibility	**0.33**	Cause	0.13	0.13	2
Stakeholder/ User	0.32	Cause	Supply chain collaboration	**0.35**	Effect	0.11	0.11	5
			Business models	**0.30**	Cause	0.09	0.09	9
			Familiarity with digital enabler technologies	**0.36**	Effect	0.11	0.11	4

Note: Imp: Importance, C/E: Cause / Effect, O.I: Overall Importance, N.O.I: Normalized Overall Importance.

Results and Discussion

This section will provide the results of the case study with further causal relationship investigation between criteria and sub-criteria. Figure 3 represents the distribution of sub-criteria in terms of the magnitude of their effects on DT adoption. As Figure 3 states, the most crucial challenges for DT in SA are obtained as *"Technological infrastructure"*, *"Compatibility,"* and "*Interdisciplinary collaboration".* As the System component is obtained as the essential challenge criteria, the two of the highly ranked criteria belong to the System dimension.

On the other hand, only investigating criteria ranking or prioritization is not enough to create a deeper understanding of DT technology and its challenges for SA. For that purpose, (D-R) values for each expectation are examined, and cause-effect relations are obtained for challenges. If *(D-R)>0,* it means that the degree of affecting others is more substantial than the degree of being affected. Therefore, Figure 4 shows both *(D+R)* and *(D-R)* values for each main criterion and sub-criteria.

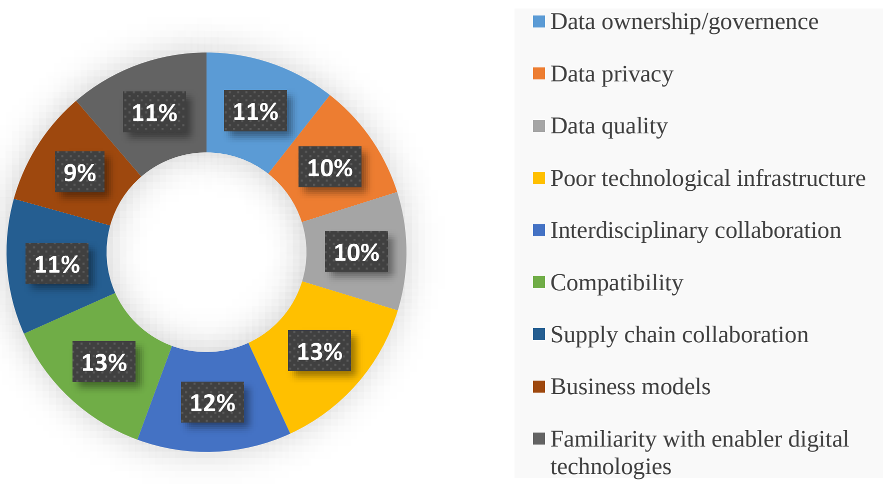

Figure 3: Effects of sub-criteria on DT adoption in SA.

The main criteria consist of three dimensions: Data, System, and Stakeholders/Users. When the causal relations are investigated between them, the System component, having a positive (D-R) value, affects the other two components. System and Data have a more significant relationship than System and Stakeholder/User dual. Compared to Stakeholder/User, Data is more susceptible to being affected by the System. Therefore, evaluating the System and Data components together is important for using DT technology in SA.

Under the System component, detected sub-criteria are: Technological infrastructure, Interdisciplinary collaboration, and Compatibility. Among three sub-criteria Technological infrastructure has the highest importance, but it is affected by Interdisciplinary collaborations. Hence, in order to obtain an efficient DT adoption in SA, generating strategies to improve interdisciplinary collaborations is a great necessity. The details of the causal relationships are provided in Figure 4.

This case study, with the expert evaluations, reveals the essential challenges for DT in SA. Investigating and analysing these challenges may help policymakers or practitioners create a strategical roadmap during their technology transfer processes.

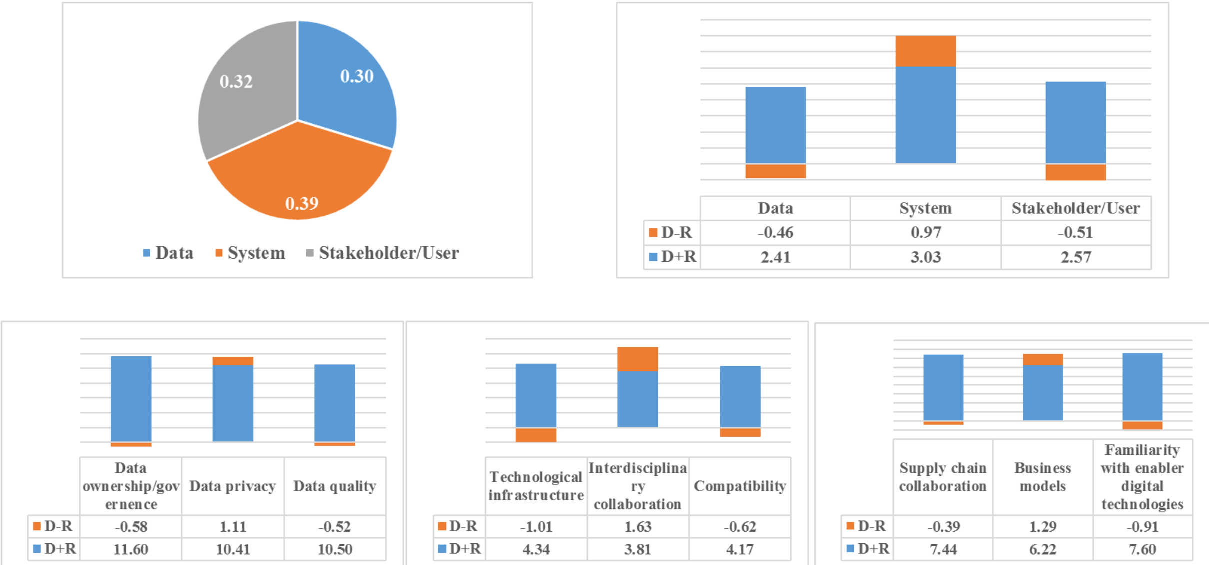

Figure 4: D+R and D-R values for main criteria and sub-criteria.

Conclusion

This paper suggests the MCDM methodology investigating DT technology challenges in the field of SA. The SA area is chosen thanks to its critical importance for creating resilient and sustainable production systems. Since agriculture is civilization's most critical production network, its digital transformation should be addressed carefully. Therefore, DT technology is chosen to be investigated in this paper as one of the enabler technologies. The DT technology is the mutual use of digital technologies such as remote sensing, IoT, and simulation. With its integrated structure, DT can help farmers to create a virtual twin of their physical entities in the virtual space. Accordingly, generating strategies and planning the production can be controlled by running some simulations with the collected data from the field.

By generating DT adoption challenges, this paper aims to create a deeper understanding of DT and its applications in SA. The suggested MCDM methodology is integrated with the 2-TL model to use linguistic variables. Linguistic variables can help DMs to work with variables closer to the human cognitive process and better analyze the DT technology and its use in SA.

In this study, the main limitation is the number of DMs used in the case. The number of DMs can be augmented to reach a more objective solution. Also, for future studies, a large group decision-making model can be applied to the same problem to cover more end-users and obtain real stakeholder opinion for expectation weighting.

Acknowledgments

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The Economic Performances of Different Trial Designs in On-Farm Precision Experimentation: A Monte Carlo Evaluation

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Abstract

On-farm precision experimentation (OFPE) has expanded rapidly over the past years. While the importance of efficient trial designs in OFPE has been recognized, the design efficiency has not been assessed from the economic perspective. This study reports how to use Monte Carlo simulations of corn-to-nitrogen (N) response OFPEs to compare economic performances of thirteen different OFPE trial designs. The economic performance is measured by the profit from implementing the N "prescription" (i.e., estimated site-specific economically optimal N rates) provided by analysing the OFPE data generated by a trial design. Results showed that the choice of trial design affects the final economic performance of OFPE. Overall, the best design was the Latin square design with a special pattern of limited N rate "jump" (LJ), which had the highest average profit and lowest profit variation in almost all simulation scenarios. The economic performance of the high efficiency fixed-block strip design (SF1) was only slightly lower than that of LJ, and could be a good alternative when only strip designs are available. In contrast, designs with gradual trial rate changes over space were less profitable in most situations, and should be avoided. Those results were robust to various nitrogen-to-corn price ratios, yield response estimation models, and field sizes used in the simulations. It was also found that the statistical efficiency measures of trial designs roughly explained the designs' economic performances, though there are still much part remaining unexplained.

Keywords

On-farm precision experimentation, field trial design, Monte Carlo simulation, economic performance, economically optimal nitrogen application rate.

Presenter Profile

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Introduction

Over the past few years agricultural scientists have been increasingly designing and implementing a revolutionary kind of agronomic field trial, generally identified as *on-farm precision experimentation* (OFPE). In OFPE, researchers and farmers collaborate to run agronomic experiments, using variable rate input technology with GPS to change input rates over multi-hectare farm fields, and using yield monitors to gather geo-spatial yield data at harvest. Because OFPE implementation is largely automated—the machine operator basically "just drives"—trial costs are dramatically lower than in traditional "small-plot" agronomic field trials (Panten, et al. 2010; Piepho et al. 2011; Bullock et al. 2019; Alesso et al. 2020; Lacoste, et al. 2022). Figure 1 presents three maps to illustrate an OFPE conducted in 2020 on a 58.8-ha DeKalb County, Illinois cornfield by the Data-Intensive Farm Management Project (Bullock, et al. 2019). The left-hand panel shows the OFPE's design, which randomized nitrogen fertilizer application rates over space. The trial design was comprised of 287 rectangular plots, each of which was 24.4 m wide (the width of the urea spreader) and between 56.9 and 73.2 m long. Each plot was assigned one of the seven experimental application rates: 83, 91, 99, 111, 119, 127, and 139 kg ha 1. The middle panel of Figure 1 shows that the "as-applied" N application rates accurately followed the design. The right-hand panel of Figure 1 shows a map of the field's measured yield values.

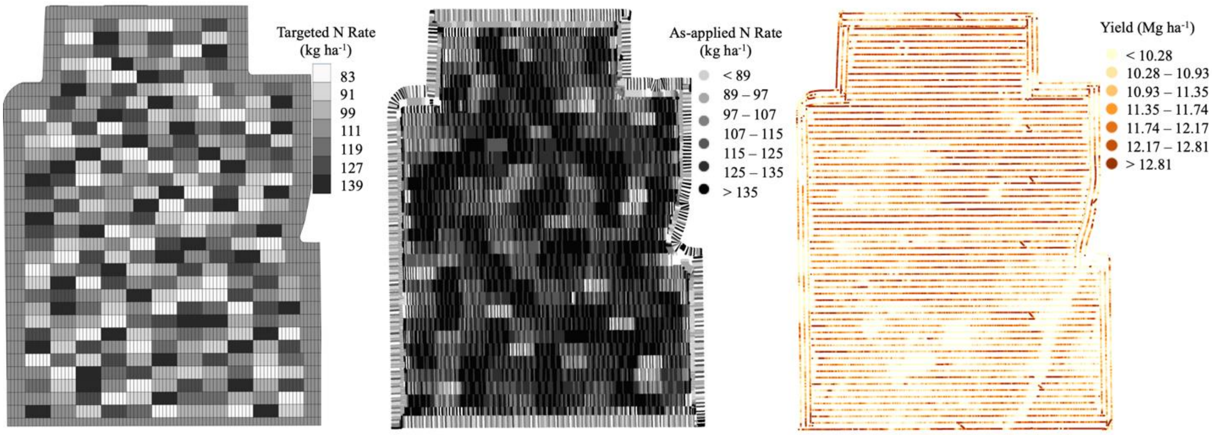

Figure 1. Trial design, as-applied map, and yield map, from an N-rate-on-corn OFPE conducted on a 58.5-ha field in DeKalb County, Illinois, 2020.

A principal aim of generating OFPE data is to empirically estimate site-specific yield-to-input-rate response functions. Knowledge of site-specific yield response functions can allow the generation of profit-increasing site-specific input application rate recommendations. Agricultural scientists have been working to understand yield response to inputs using small-plot agronomic field trial data for more than a century, and have always been concerned about optimal field trial design (e.g., Smith 1907; Spillman 1923; Eden and Fisher 1929). In fact, R.A. Fisher invented fundamental aspects of modern statistical analysis to analyse data from small-plot field trials (Fisher 1926; Box 1976, 1978). But OFPE data is different from small-plot field trial data in important ways and, much in the way that the generation of small-plot field trial data necessitated Fisher's work on efficient small-plot field trial design and analysis of the data, incoming OFPE data necessitates increased research on efficient OFPE design and statistical analysis.

Increasing Prevalence of On-Farm Precision Experiments

OFPE began near the close of the 20th Century with pioneering independent research by Cook and Bramley (1998) in Australia, by Donald Bullock and Ronald Milby in the USA (Bullock, et al., 2002; Rund, 2003; Bullock, 2021), by Doerge and Gardner (1999) in the USA, and by Lowenberg-DeBoer and Aghib (1999) in the USA. A handful of OFPEs were reported conducted in the early 2000s (Pringle et al., 2004; Panten et al., 2010; Whelan et al., 2012), but OFPE has expanded rapidly over the past five years or so. Recognizing this expansion, the International Society of Precision Agriculture organized an October 2021 conference in Montpelier, France with the theme of on-farm experimentation (International Society of Precision Agriculture, 2021). The USDA's Natural Resource Conservation Service's Conservation Innovation Grant program awarded $25 million to on-farm trials research, including a $4 million grant to the Data-Intensive Farm Management Project (Bullock, et al., 2019) which is funding researchers from fourteen US universities to run 360 OFPEs from 2021 through 2023 in thirteen US states, and to develop cyber-infrastructure to be used by commercial crop consultants and their farmer-clients to run future OFPEs and use the data for input application management (USDA-NRCS 2020). The USDA's National Institute for Food and Agriculture's National Information Management & Support System has begun funding a Multistate Research Project titled "Frontiers in On-farm Experimentation," which brings a multidisciplinary group of US-based scholars to conduct OFPEs and research about OFPEs (National Information Management and Support System, 2021).

Field Trial Design Efficiency

Research into the statistical efficiency of agronomic field trial designs has a long and prestigious history; indeed, R.E. Fisher developed much of the framework of modern statistical theory and applied experimental practices in his work in the 1920s and 1930s with agronomic small-plot field trial data from the Rothamsted Research Station (Box 1980). But the bourgeoning of whole-field OFPE is bringing new questions about trial design efficiency to the fore. While long-established concepts about how the geometric properties of field trial designs, such as "spatial balance" and "evenness" can also be used to understand OFPE design efficiency, differences between small-plot and OFPE trials in plot geometry and the spatial heterogeneity of field characteristics call for re-examination of some of the conclusions reached in the historical literature on the statistical efficiency of agronomic field trial design.

Many previous studies of the efficiency of on-farm field trials (e.g. Alesso et al, 2019, 2000) have examined the effects of trial design on the statistical accuracy (in terms of RMSE, Type I error, etc.) of yield response parameter estimators. In the present report, we instead employ an economic measure of trial design efficiency. The idea is that, a better design should generate higher quality trial data to support more accurate yield response estimations, and consequently result in economically superior input management recommendations. Using economic measures of field trial design efficiency allows us to discuss our research results in dollars and cents, terms easily understood by statisticians and non-statisticians alike.

Materials, Data and Methods

Simulated Experimental Field

Field Layout

We conducted Monte Carlo simulations of OFPEs to examine trial design efficiency. The simulations generated data on site-specific corn yield response to N fertilizer application rates on a simulated field, illustrated in Figure 2. The field was 864 meters long and 432 meters wide, covering an area of approximately 37.3 hectares, which is a typical size for row crop production in the U.S. Corn and Soy Belt. The field was assumed to be farmed in the direction of its long side, and was partitioned into a 144 × 72 grid of 6m × 6m "cells", where the field "characteristics" values were assumed spatially uniform within each cell but spatially stochastic among cells. Every trial design featured six targeted N rates. The width of the N applicator was assumed to be 18 m. As is the case currently in OFPEs, it was assumed that yield monitor technology could not accurately record large changes in yield over short distances, but rather required time and space to adjust its measurements accurately. It was assumed that when the harvester passed between plots assigned differing N rates, the yield monitor had to pass through a 12m "transition zone" before accurately measuring yield, but that thereafter could accurately record yields within 18m × 12m "subplots" made up of a 3 × 2 grid of cells. The N applicator was also assumed to require time and space to adjust the applied N rates. N trial rates were assigned to 72 m (12-cell) long "plots." The N applicator was assumed to be able to accurately apply N subplot-specifically (but not cell-specifically). Data from transition zones were not used in the statistical analyses, but each of the field's 288 N plots provided data from five subplots, meaning that useful data was generated on 1,440 subplots after excluding the transition areas. Each subplot contained six cells. Transition areas included 1728 cells, so the field contained 1,440×6 + 1728 = 10,368 cells in total.

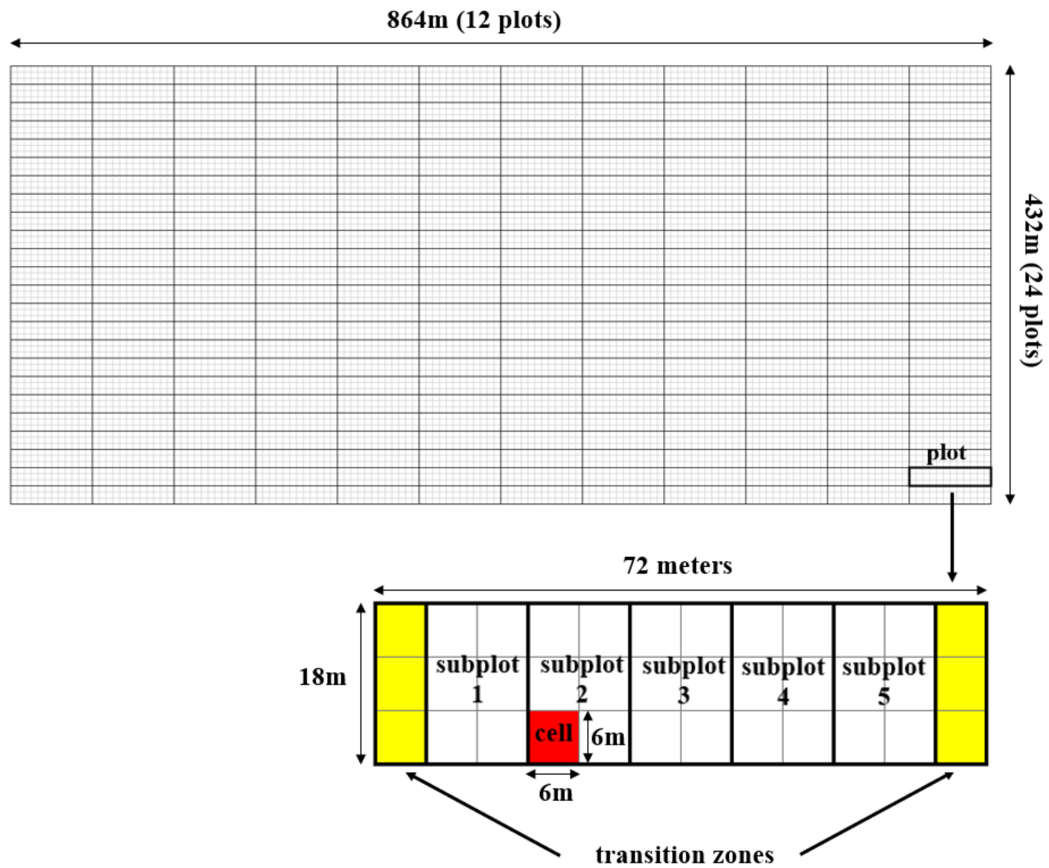

Figure 2. Experimental field layout and definition of spatial units

True Yield Response Function

We assumed that the true underlying corn yield response to nitrogen (N) fertilizer followed a quadratic-plateau functional form with an additive disturbance term:

$$f(N; \beta_0, \beta_1, \beta_2) = \begin{cases} \beta_0 + \beta_1 N + \beta_2 N^2 + \varepsilon, & N < K \\ \text{plateau} + \varepsilon, & N \geq K \end{cases} \qquad (2.1)$$

where $K = -\beta_1/(2\beta_2)$ is the critical *N* application rate above which the yield maintains a $\text{plateau} = \beta_0 + \beta_1 K + \beta_2 K^2$. The quadratic-plateau form is widely used by agronomists to model corn yield response to nitrogen (e.g., Cerrato and Blackmer 1990; Bullock and Bullock 1994; Holman, et al. 2019).

Spatial Distributions of True Response Parameters (“Field Characteristics”)

In each simulation, the model’s “true” triplet of response parameters (β_0, β_1, β_2) varied by cell. Their spatial distributions were derived using a Gaussian random field with a variogram range of 600 m (i.e., there was no spatial correlation between parameters of cells more than 600 m apart). Figure 3 shows the maps from one simulation’s response parameters. The spatial distributions of response parameters may be thought of and treated as representing the underlying spatial variability of field characteristics variables (such as soil clay content or topographical slope) that may influence yield directly or through interaction with N.

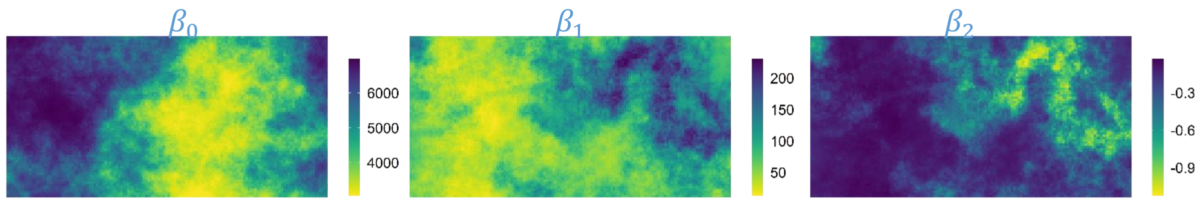

Figure 3. Spatial distribution of true yield response parameters (or “field characteristics”) in one simulation

Trial Designs

Each simulated OFPE included six targeted trial N rates (N_1, N_2, N_3, N_4, N_5, N_6), which were set at the 0%, 20%, 40%, 60%, 80%, and 100% percentiles of the experimental field’s true cell-level critical N rate, *K*, to ensure a range of trial rates adequate to cover most locations’ yield response plateau points. Sets of targeted N rates differed only slightly across simulations, and averaged approximately 80, 128, 154, 190, 224, and 269 kg ha^{-1}.

Figure 4 displays the thirteen types of trial designs considered. Selections of types were based on two considerations. First, we included OFPE designs currently in frequent use, which are randomized strip, grid, and Latin square designs. Second, beyond the randomized designs, we constructed high-efficiency and low-efficiency fixed pattern strip, grid, and Latin square designs using four of the statistical measures developed in the agronomic literature to measure the “efficiency” of the spatial pattern of a design’s trial rates distribution. Those measures are: (1) evenness of spatial distribution (Piepho et al., 2018), (2) spatial balance (van Es et al., 2007), (3) Moran’s I, and (4) gradation (a measure created by the authors of this paper). We describe these measures in further detail in Appendix.

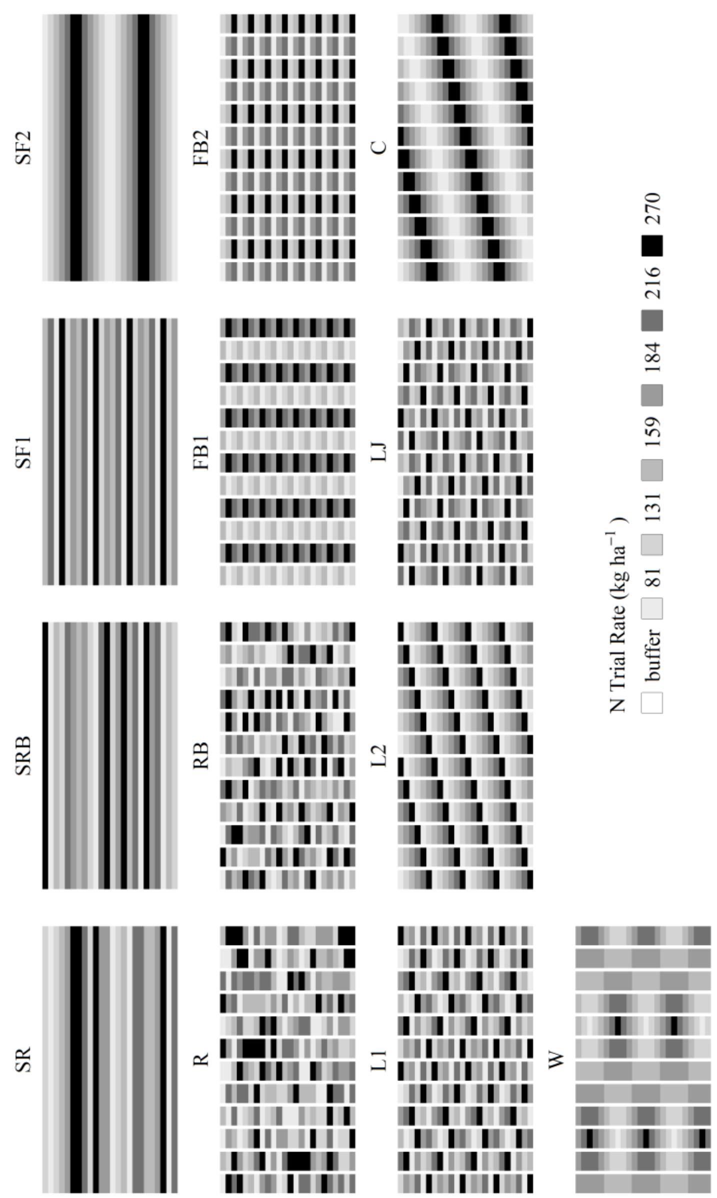

Figure 4. Trial design types

Strip Designs

Strip trials have been frequently run in on-farm research over recent decades and are commonly deployed in current research (e.g., Hicks, et al. 1997; Kyveryga, et al. 2018). Typical strip trial designs allocated targeted application rates among but not within field-length, applicator-width strips of the field. Advantages of strip trial design are that they are simple and can be implemented wihout variable-rate application equipment. In our simulations the field contained 24 strips, each 18m (three cells) wide and 864m (144 cells) long. We examined four kinds of strip design.

(1) In *completely randomized strip* designs ("**SR**") each of the six N target rates was randomly assigned without replacement to four of the field's 24 strips.
(2) In *randomized complete block strip* designs ("**SRB**") the field was partioned into four "blocks," each containing six contiguous strips, to each of which was randomly assigned a targeted N rate without replacement. Blocking is a classical design scheme in agricultural field trials, and our procedures allowed us to estimate its economic benefits.

(3) In the *high efficiency fixed block strip* design **("SF1")** the targeted N rates were spatially patternized to be (N_3, N_5, N_1, N_6, N_2, N_4) within each six-strip block, as illustrated in the upper panels of Figure 5. That patternized block was replicated for the remaining of the field (which is why we named it as "fixed block"). In total there are 720 possible blocked strip trial patterns, and the **SF1** chosen here has the highest average of the field's four statistical "efficiency" measures.

(4) In the *low efficiency fixed block strip* design **("SF2")** the strips' targeted N rates followed the patterns of (N_1, N_2, N_3, N_4, N_5, N_6) and (N_6, N_5, N_4, N_3, N_2, N_1) in alternating blocks, as illustrated in the bottom panels Figure 5. Among the 720 possible blocked strip trial patterns, **SF2** has the lowest average of the field's four statistical "efficiency" measures.

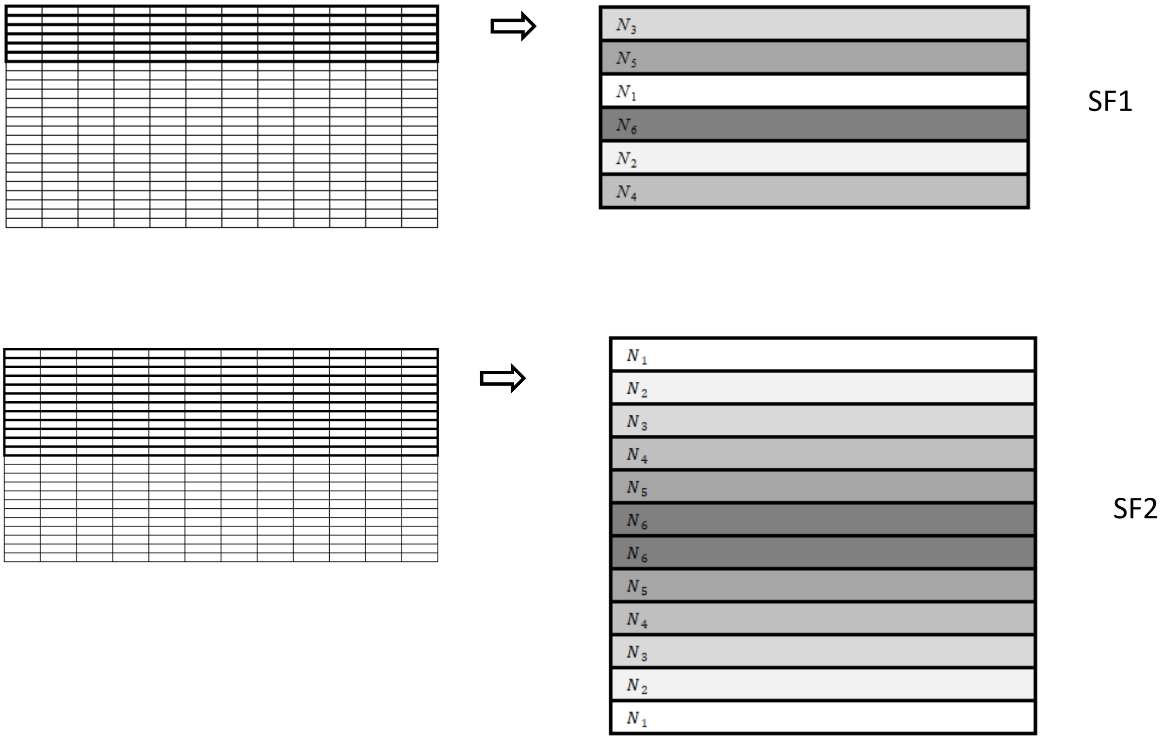

Figure 5. The SF1 and SF2 block patterns

Gridded Designs

In gridded trial simulations, targeted N rates were varied among the 72m-long, 18m-wide plots. Gridded trials can gain statistical advantage over strip trials by increasing the spatial variance of application rates. We examined two types of gridded designs, which we call non-Latin-square designs and Latin square designs.

Non-Latin-square Gridded Designs

(5) In *completely randomized gridded* designs ("**R**"), each of the six N target rates was randomly assigned to 48 of the 288 plots. Agronomists rarely employ completely randomized designs in agricultural field trials, but we used it as a benchmark against which to measure the economic benefit of blocking.

(6) In *randomized complete block gridded* designs ("**RB**") blocks comprised six plots organized in a 3-row and 2-column layout. The six N trial rates were randomly assigned without replacement to the six plots within each block. **RB**s are widely used small-plot agricultural field trials (e.g., van Es et al. 2007; Ahmad et al. 2018; Adhikari et al. 2021).

(7) In *high efficiency fixed block gridded designs*(“**FB1**”) blocks comprised six plots organized in a 3-row and 2-column layout, as in the RB design, but in each block the six N trial rates were assigned in a fixed pattern, with N_3, N_4 in the first row, N_1, N_6 in the second, and N_2, N_5 in the third, as illustrated in the left-hand panel of Figure 6. Out of the 720 possible patterns of the six N rates allocation within a block, **FB1** generates the highest average of the four statistical “efficiency” measures for the whole field’s N rate spatial layout.

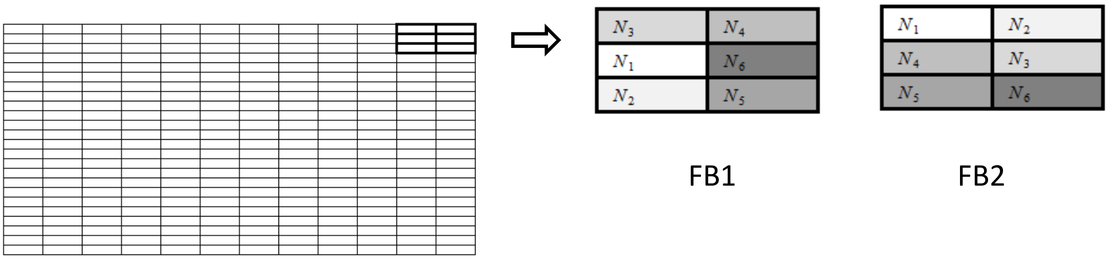

Figure 6. The FB1 and FB2 block patterns

(8) In *low efficiency fixed block gridded designs*(“**FB2**”) the within-block pattern was with N_1, N_2 in the first row, N_4, N_3 in the second, and N_5, N_6 in the third, as illustrated in the right-hand panel of Figure 6. This pattern generates the lowest average of the four statistical “efficiency” measures for the whole field’s N rate spatial layout out of the 720 possible patterns of the six N rates allocation within a block.

Latin Square Designs

A Latin square design with *n* targeted rates is defined as an array of $n \times n$ plots in which each rate is assigned exactly once in each row and each column. In our simulations, blocks were 6×6 arrays of 36 plots, the field was partioned into a 4×2 array of blocks, and the spatially arrangements of the six N rates were identical (“fixed”) among the eight blocks. In the trial design statistics literature Latin square designs have long been believed to be efficient, but are still not widely used in agronomic experiments (Fisher 1926; Box 1980; Preece 1990). We considered three specific Latin square designs.

(9) The *high-efficiency Latin square design* (“**L1**”) had the highest average efficiency ranking among all Latin square designs of order 6. Figure 7 (“L1”) displays the N rate pattern in one block of an **L1** trial.

(10) The *low-efficiency Latin square design* (“**L2**”) had the lowest average efficiency ranking among all Latin square designs of order 6. Figure 7 (“L2”) displays the N rate pattern in one block of an **L2** trial.

(11) *The rate jump constrained Latin square design* (“**LJ**”) restricted the size of changes in targeted N rates between adjacent plots within swaths. **LJ** was included in the analysis to examine the costs caused by the common limitation of variable rate input applicators being unable to make large changes in application rates over relatively short distances. We conducted the similar average “efficiency” measure ranking on all Latin squares that satisfy this “rate-jump” restriction, and used the one with the highest average efficiency ranking,. Figure 7 (“LJ”) shows the block pattern of **LJ**.

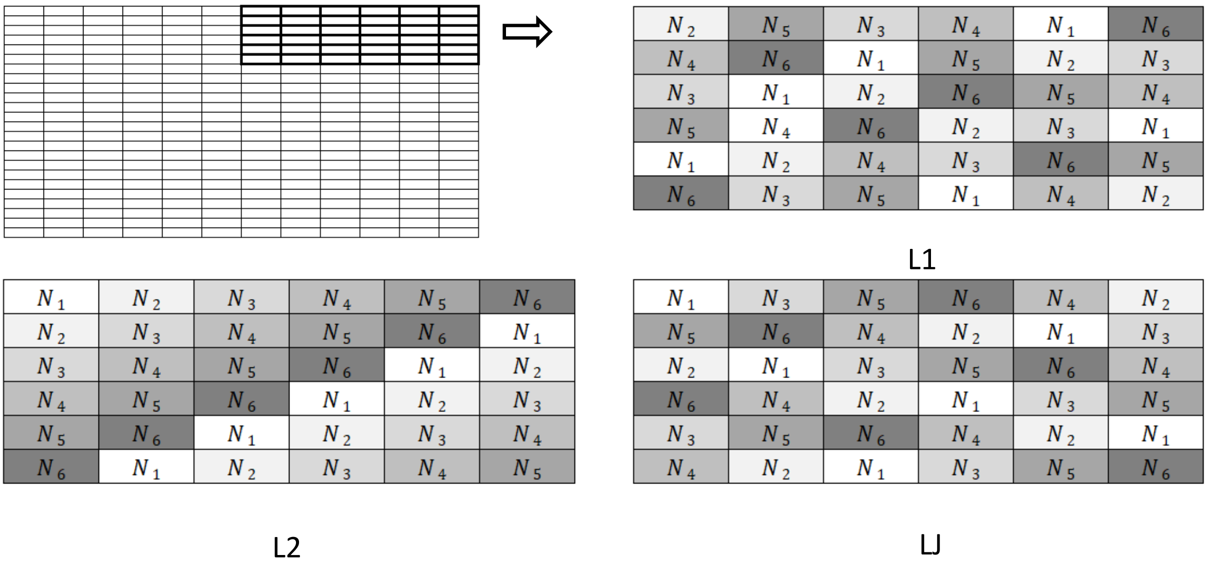

Figure 7. Block pattern of the Latin square designs

Other designs

We also considered two designs uncommonly used in reported research. The designs feature very gradual changes in trial rates over space. We included them for purposes of comparison with the other eleven designs.

(12) In the cascade plot design ("**C**"), the N rates changed smoothly from N_1 to N_6, and then back from N_6 to N_1, in both the row and column directions.

(13) In the wave design ("**W**"). It is even more extreme than the Cascade design, such that the N rates changed gradually row, column, and diagonal directions, This design was mentioned in Bramley et al (1999).

Yield Data Simulation Process

While N target rates were assigned by plot, as-applied N rates differed among cells within a plot because the N rate in each cell equalled the target rate plus a disturbance term. The distribution from which these disturbance terms were drawn was estimated from DIFM data. Each cell's yield value was generated in each simulation round by using the value of the cell's β parameters, the cell's assigned N application rate and a value of the spatially autocorrelated yield disturbance term ε in the yield response function defined in (2.1). ε was simulated using the Gaussian random process. The sizes of the yield errors were also calibrated to match the DIFM empirical yield disturbances. Each subplot's simulated cell-level yields were then averaged to obtain the observational unit of yield used in the analysis.

Data Analysis and Economic Evaluation

In each Monte Carlo round the subplot-level averaged simulated yield and trial N rates data were used to estimate the site-specific yield response functions. Three estimation models were used to examine the robustness of the results with respect to estimation methods: (1) the geographically weighted regression model ("GWR"), (2) the boosted regression forest model ("BRF"), and (3) the multi arm causal forest model ("MACF").. The functional form of yield response in the local regressions in the GWR models was assumed to be quadratic. GWR with nonlinear regressions is currently under development (e.g., Lambert and Cho (2022) has developed a linear-plateau GWR model), but the quadratic-plateau GWR is not yet available.

The coefficient estimation of the quadratic term in the GWR model was highly sensitive to sample errors. To alleviate this problem, the quadratic coefficient was held constant in the GWR simulations following Trevisan et al. (2021). However, GWR model only utilizes the minimum information (yield, N rates, and location coordinates) to estimate site-specific response functions, and is not guaranteed to be the most accurate modelling technique. While the better site-specific yield response models are still under development, in this study two machine learning models (BRF and MACF) with perfect field characteristics information (represented by the true response parameters (β_0, β_1, β_2)[7]) were used to mimic the more ideal modelling techniques that can possibly be achieved in the future.

Estimated Subplot-specific Yield Response Functions

For cell *i* ∈ {1, 2, …, 10368}, let $\left(\beta_0^i, \beta_1^i, \beta_2^i\right)$ denote the true value of the field characteristics vector and let $f^i(N) \equiv f\left(N; \beta_0^i, \beta_1^i, \beta_2^i\right)$ of equation (2.1) denote the cell-specific yield response function. In the OFPE practice the N trial rate and yield data are only available at subplot level. Therefore, the estimated yield response functions are subplot-specific, denoted $\hat{f}^j(N)$ for a generic subplot *j*, *j* ∈ {1, 2, …, 1440}. The GWR model generated an estimated quadratic response function for each subplot j as $\hat{f}^j(N) = \hat{\beta}_0^j + \hat{\beta}_1^j N + \hat{\beta}_2^j N^2$ where $\left(\hat{\beta}_0^j, \hat{\beta}_1^j, \hat{\beta}_2^j\right)$ denoting the estimated parameter values at subplot *j*. On the other hand, the machine learning models, BRF and MACF, do not require the assumption that the researcher knew the true form of the yield response function. The predicted yield and N rate relationship for each subplot *j*, $\hat{f}^j(N)$, is in a numerical manner by decision trees.

Estimated Subplot-specific Economically Optimal N Rates

In each subplot *j*, the estimated subplot-specific economically optimal nitrogen rate (EONR) was defined as,

$$\widehat{\mathrm{EONR}}^{\mathrm{j}} = \underset{\mathrm{N}}{\operatorname{argmax}} \left[\mathrm{p}\hat{\mathrm{f}}^{\mathrm{j}}(\mathrm{N}) - \mathrm{wN}\right], \qquad (2.2)$$

where *p* was the corn price and *w* was the nitrogen fertilizer price, and the derivation of $\hat{f}^j(N)$ depended on the estimation methods described above. Let R_x denote $\left\{\widehat{EONR}^1, \dots, \widehat{EONR}^{1440}\right\}$, the set of estimated subplot-specific economically optimal N application rates (the "prescription") provided by the estimation methodology used to analyse the data from the on-farm experiment.

Profits from Following the Prescription Provided by an On-farm Precision Experiment

For a generic cell *i* in subplot *j*, the true yield generated from following the R_x was calculated by substituting each subplot estimated $\widehat{\mathrm{EONR}}^{\mathrm{j}}$ into its "true" cell-specific yield response function, $\mathrm{f}^{\mathrm{i}}(\mathrm{N})$ of equation (2.1). Since EONRs were estimated subplot-specifically, each cell *i* in subplot *j* has the same estimated value of $\widehat{\mathrm{EONR}}^{\mathrm{j}}$. For notational purpose we denote the true response function $\mathrm{f}^{\mathrm{i}}(\mathrm{N})$ of cell *i* in subplot *j* as $\mathrm{f}^{\mathrm{j,i}}(\mathrm{N})$. The resulting actual per-hectare profit from applying the R_x was therefore:

[7] That is like to mimic a situation that we know the field characteristics variables that can perfectly predict the yield response parameters, and can also collect those variables data in perfect accuracy.

$$\Pi^{Rx} = \frac{1}{8640}\sum_{j=1}^{1440}\sum_{i=1}^{6}\left[pf^{j,i}(\widehat{EONR}^j) - w\widehat{EONR}^j\right], \qquad (2.3)$$

where 1440 × 6 = 8640 was the total number of cells in the subplots (which did not include cells in the transition zones) of the experimental field.

Π^{Rx} defined above is the actual profit from implementing the on-farm trial's R_x. It comes from applying the estimated subplot-specific EONRs to the field, not from applying the true subplot-specific EONRs, defined as

$$EONR^j = \underset{N}{argmax}\sum_{i=1}^{6}\left[pf^{j,i}(N) - wN\right], j = 1, 2, \ldots, 1440. \qquad (2.4)$$

Let Π^{true} denote the profits that could be earned from the field if the producer knew every cell-specific yield response function and had the technological capability to apply N subplot-specifically:

$$\Pi^{true} = \frac{1}{8640}\sum_{j=1}^{1440}\sum_{i=1}^{6}\left[pf^{j,i}(EONR^j) - wEONR^j\right]. \qquad (2.5)$$

Let $\Delta\Pi$ denote the difference in between Π^{Rx} and the true maximum profit:

$$\Delta\Pi = \Pi^{Rx} - \Pi^{true}. \qquad (2.6)$$

Note that $\Delta\Pi$ is always negative, but when Π^{Rx} is closer to Π^{true} profits from the information garnered from the OFPE data are higher.

Three price ratios (nitrogen fertilizer price divided by corn price, both in \$/kg) were used in the simulations: 4.16 (low), 6.56 (medium), and 10.35 (high). They were obtained by taking the values at the fifth, fiftieth, and ninety-fifth percentiles of historical monthly price ratios from 1990 to 2022 (National Agricultural Statistics Service; DTN Retail Fertilizer Trends). The April 2022 corn price of \$0.28/kg was used in the simulation results, and nitrogen was assigned prices of approximately 4.16×0.28 = \$1.16/kg, 6.56×0.28 = \$1.84/kg, and 10.35×0.28 = \$2.90/kg. The discussion below is based on the simulation results when assuming the \$1.84/kg price of nitrogen fertilizer. That the N price has never actually been as high as \$2.90/kg price did not affect the EONR estimations since they were determined by the relative nitrogen-corn price ratio rather than absolute the prices. The absolute profit values Π^{Rx} and Π^{true}could be over- or under-estimated by extreme N prices, but those over- or under-estimations were linear scale-ups or scale-downs of the normal profit values and did not affect the economic performance rankings of trial designs.

Results and Discussion

Comparisons of Designs and Key Questions Addressed

Figure 8 shows boxplots of the simulated *ΔΠ* of the thirteen experimental designs from one thousand rounds of simulation. The diagram was based on a medium price ratio (N price divided by corn price, both in \$/kg) of 6.56. Profits were calculated based on three site-specific yield response models (GWR, BRF, and MACF). The values above each boxplot denote simulations' mean *ΔΠ*.

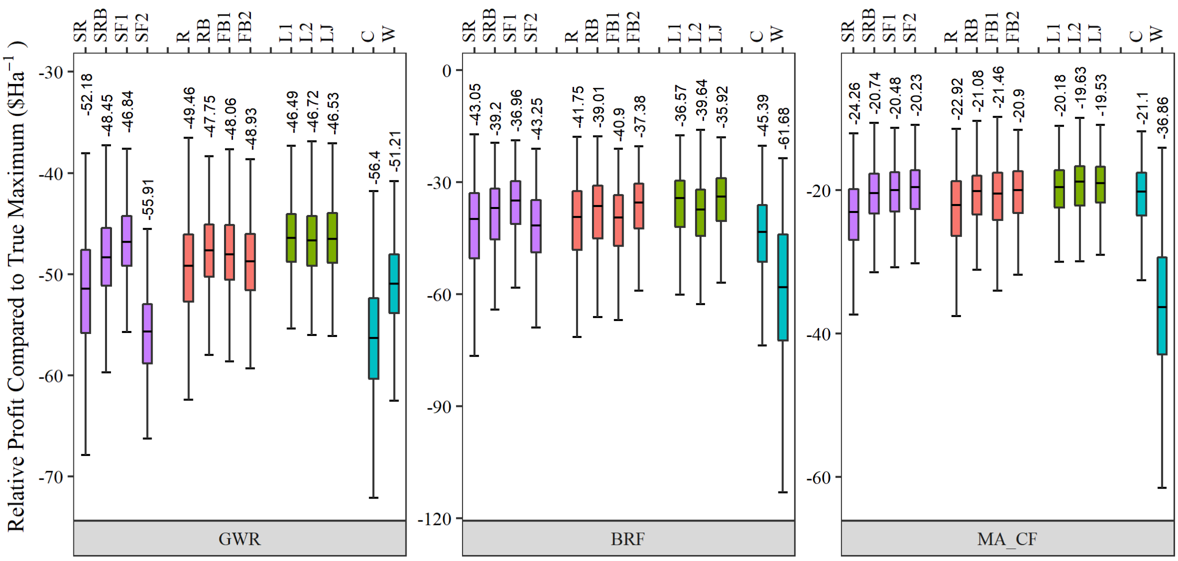

Figure 8. Boxplots of simulated profits from one thousand rounds of simulation for the thirteen experimental designs

Simulation results provide quantitative insight into several key questions related to the economic performances of trial designs. Answers are based on comparisons of profits generated from one thousand rounds of simulations of a 31.3 ha field and a price ratio of 6.56. Simulations were also run under other field size and price scenarios, and instances in which any scenario significantly affected the conclusions stated below are noted.

Is blocking economically beneficial? Yes.

Blocking designs have been commonly regarded as statistically superior ("more efficient") to completely randomized designs. Our simulation results demonstrated that blocking designs also have higher economic returns.

For strip designs, profits from blocking (that is, from using **SRB** instead of **SR**) were approximately $3.5 to $4/ha under all models. For the gridded designs, profits from blocking (that is, from using **RB** instead of **R**) were approximately $1.7 to $2.7/ha under different models. Blocking also lowered the standard deviations of the $\Delta\Pi$ estimations under all models.

(2) *Is patternizing within-block targeted application rates economically beneficial?* Sometimes, but it depends on the pattern and estimation model used.

For strip designs, the high efficiency fixed-block strip design (**SF1**) was $0.3/ha to $2.2/ha more profitable than the randomized block strip design (**SRB**), depending on the estimation model used. The standard deviations of profits of **SF1** were also smaller than **SRB**. But low efficiency fixed-block strip design (**SF2**) was less profitable than **SRB** under GWR (-$7.5/ha) and BRF (-$4/ha) models, while slightly more profitable under the MACF ($0.5/ha) model.

For the gridded designs, the low efficiency fixed-block design (**FB2**) was slightly more profitable ($0.2 to $1.6/ha) than the randomized block design (**RB**) under BRF and MACF models, but the high efficiency fixed-block design (**FB1**) was slightly less profitable than **RB** under all models.

(3) *Does increasing the statistical "efficiency" of a design's spatial properties raise profits?* Sometimes, but it depends on the design type and estimation model.

The highly efficiency fixed-block strip design (**SF1**) was significantly more profitable than the low efficiency strip design (**SF2**) by as much as $9/ha under GWR model and $6/ha under BRF model, but not under the MACF model. For the gridded designs, the high efficiency fixed-block design (**FB1**) was slightly more profitable than the low efficiency design (**FB2**) under the GWR ($0.9/ha) model, but less profitable under the BRF (-$3.5/ha) and MACF (-$0.5/ha) models. For Latin square designs, the high efficiency Latin square design (**L1**) was more profitable than the low efficiency Latin square design (**L2**) under the GWR ($0.2/ha) and BRF ($3/ha) models, but less profitable under the MACF (-$0.7/ha) model.

Roughly speaking, the high efficiency designs were more profitable than their respective counterparts under the GWR and BRF models (except for **FB1** vs. **FB2** under BRF), while less profitable under the MACF model though the magnitudes of the profit difference were small. The statistical "efficiency" measures could have been effectively used as general guidelines for trial design, though caution should be exercised on cases of exceptions.

(4) *Are gridded designs better than strip designs?* Not necessarily.

Perhaps surprisingly, the high efficiency fixed-block strip design **SF1** provided similar or even slightly higher profits than the six-rate-block gridded designs (**RB**, **FB1**, or **FB2**). **SF1** profit was $0.90/ha greater than **RB** profit under GWR, $0.06/ha greater under **GWR2**GWR2, and $0.40/ha greater than **FB2** under BRF. Under MACF, **SF2** provided the highest profit, which was about $0.70/ha higher than from **FB2**. The standard deviation of profits from **SF1** were also smaller than or very close to those from **RB**, **FB1**, and **FB2**.

For strip vs Latin square gridded designs, however, the Latin square designs can be slightly more profitable. The high efficiency Latin square design (**L1**) was more profitable than the high efficiency strip design (**SF1**) for all estimation models. But the profit difference was not sizable.

(5) *Are the 6-by-6 Latin square designs better than the 6-rate blocking designs?* Yes.

The high efficiency Latin square design (**L1**) was more profitable than the six-rate-block design (**RB**, **FB1**, or **FB2**) under all models. But the profit difference was not sizable only about $7/ha under GWR, and was below $0.80/ha under the other models.

(6) *Does the inability of the machinery to change rates abruptly significantly lower the value of information from the experiments*? No.

Simulation results showed there was essentially no profit penalty from restricting the N rate "jumps" between adjacent plots in the Latin square designs. In fact, the Latin square design with constrained "jump" (**LJ**) was even slightly more profitable, and also more stable, than the best Latin square design (**L1**). The profit difference was quite small, though, at $0.04/ha from GWR, $0.35/ha from BRF, and $0.10/ha from MACF.

(7) *How did Cascade and Wave designs perform?* Poorly.

Profits from the Cascade and Wave designs were almost always the lowest among all designs. Based on GWR, Cascade design (C) profit was about $10/ha lower than the best-performing **LJ** design. Based on BRF and MACF, Wave design (W) profit was $26/ha and $17/ha lower than **LJ** design.

Overall ranking of designs and sensitivity analysis

Sensitivity to price ratios

Results above were generally robust with respect to the price ratio. Boxplot figures for profits under low and high price ratios are shown in Figures A.1 and A.2 of the Appendix. Of course, the absolute size of profit levels varied substantially with the price ratios, but the relative performances of the designs changed little.

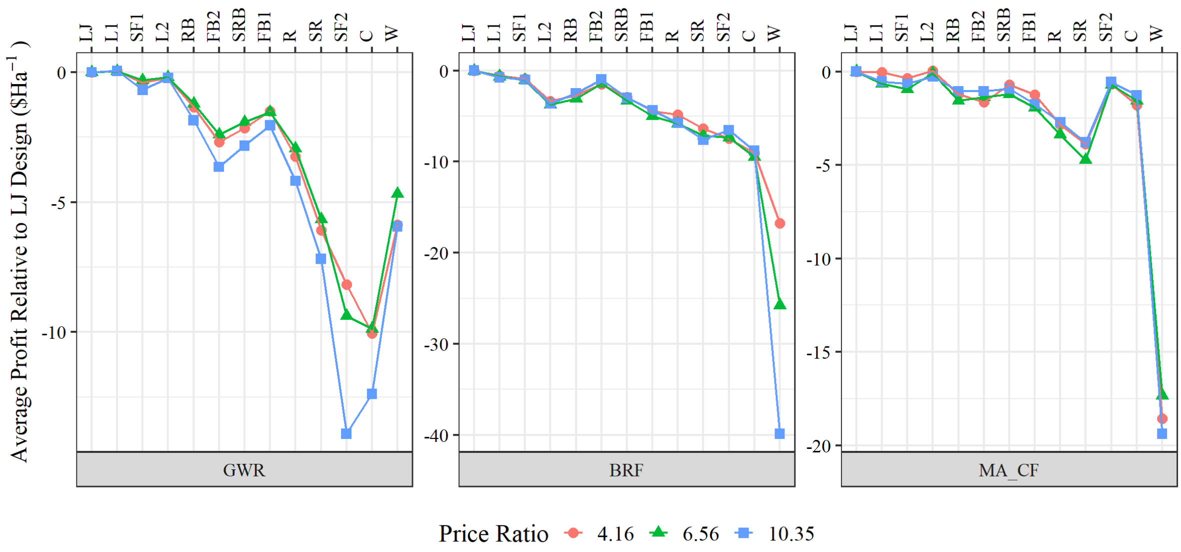

Figure 9. Average simulated profits from 1,000 rounds of simulation for the thirteen experimental designs, based on price ratios and estimation models.

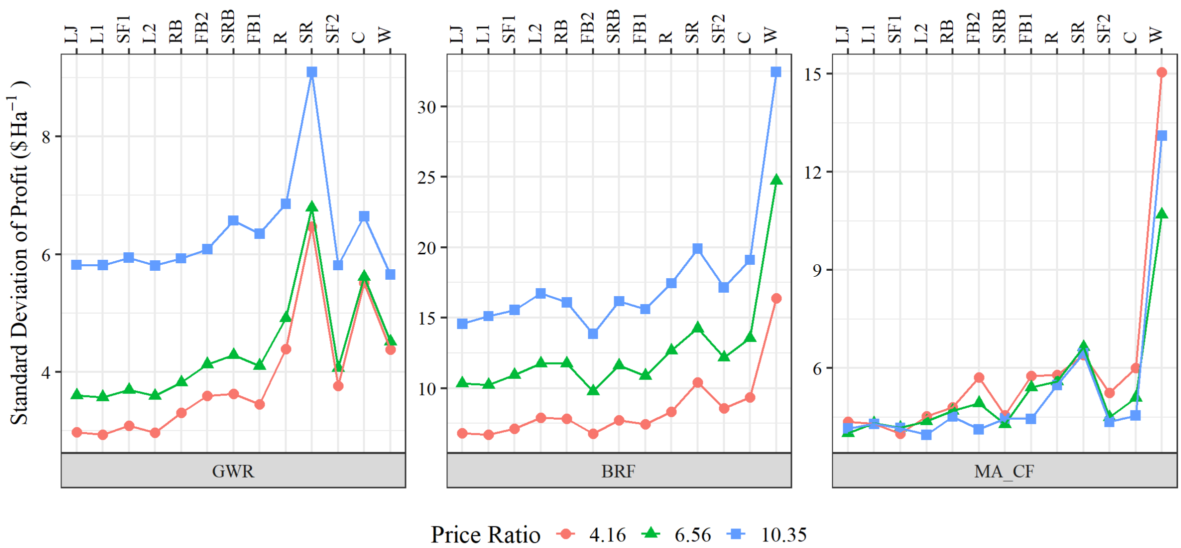

Figure 10. Standard deviation of simulated profits from 1,000 rounds of simulation for the thirteen experimental designs, based on price ratios and estimation models.

Design rankings

Figure 9 plots average $\Delta\Pi$ of each design for all estimation models and price ratios (the average profit values were extracted from Figures 8, A.1, and A.2), and uses the profit of **LJ** design as the benchmark. The values in Figure 9 shows the relative economic performance of each design compared to design **LJ**. The horizontal ranking of designs was based on the pooled average $\Delta\Pi$ over all estimation models and price ratios, which is {**LJ**, **L1**, **SF1**, **L2**, **RB**, **FB2**, **SRB**, **FB1**, **R**, **SR**, **SF2**, **C**, **W**}. Similarly, Figure 10 plots the standard deviations of $\Delta\Pi$ following the same horizontal ranking of designs.

LJ was the best design (highest average profit, and lowest standard deviation of profit) for all price ratio and model scenarios. **L1** or **L2** was in some cases a close second to **LJ**. But when taking into account the benefit from **LJ** of avoiding machinery problems by restricting abrupt N rate changes between plots, **LJ** is almost always a desirable design.

SF1 was also worth of considering given its close economic performances to **LJ** (less than $1/ha lower) but essentially no N rate changes between plots along the application direction, and therefore much lower requirements for experimental equipment.

The overall rankings of the designs were highly consistent across price ratios. The robustness of design ranking to price scenarios is especially useful as it avoids the selecting of optimal design conditional on harvesting time price that is usually difficult to predict at the time of implementing trials.

Sensitivity to estimation models

It should be noticed that the rankings of the designs varied with the estimation model used. For example, **SF2** was among the poorest performing designs under GWR, but was among the top performing designs under MACF. **RB** was more profitable than **FB2** under GWR, but less profitable under BRF, and almost identical under MACF. Other designs, such as **RB**, **FB1**, **FB2**, and **RSB**, also slightly differed in rankings across estimation models. In addition, the magnitudes of profit differences between designs were much smaller under MACF compared with other models, meaning the selection of trial design may matter less when using MACF model to derive Rx. Nonetheless, the general trends in design performance rankings were roughly similar across estimation models. Especially, the rankings of **LJ** (the top-ranked design) and **SF1** (very close to the top) were very robust to estimation models.

Sensitivity to field sizes

The design performance rankings were also highly robust to different field sizes. Figures A.3 and A.4 showed the simulation results for a 18.7 ha field, half the size of the baseline field.

The overall rankings of the design performances were similar to the baseline field results, with some slight changes. **LJ** design was still the best choice, and **SF1**'s overall ranking was even slightly better than **L1** (though the differences were quite marginal). The shapes of the trend lines of average and standard deviation of profits along the designs were still similar to the baseline field results, and therefore most of the previous conclusions hold.

Profit differences between designs were slightly larger on the smaller field for the bottom-ranked designs. For example, under the medium price ratio (6.56) the profit difference between **LJ** and **C** designs was $9.50/ha under GWR for the baseline field, and $15/ha for the smaller field. But the effects of field size on profit differences were less significant for the top-ranked designs. The standard deviations of profit were significantly larger on the smaller field than on the baseline field. Those findings may suggest the economic penalty of selecting "bad" designs increases for smaller sized fields.

Relationship between statistical efficiency measures and economic performances

We calculated the four statistical “efficiency” measures mentioned earlier (evenness of distribution, spatial balance, Moran’s I, and gradation) for all thirteen designs. In addition, we tried two extra efficiency measures of design based on as-applied N rates (instead of the target N rates), which we named as “local N rate variation” and “local accidental correlation between N rate and yield error”. Details of the two extra measures are described in Appendix Text A.1 “Statistical Measures of Designs”.

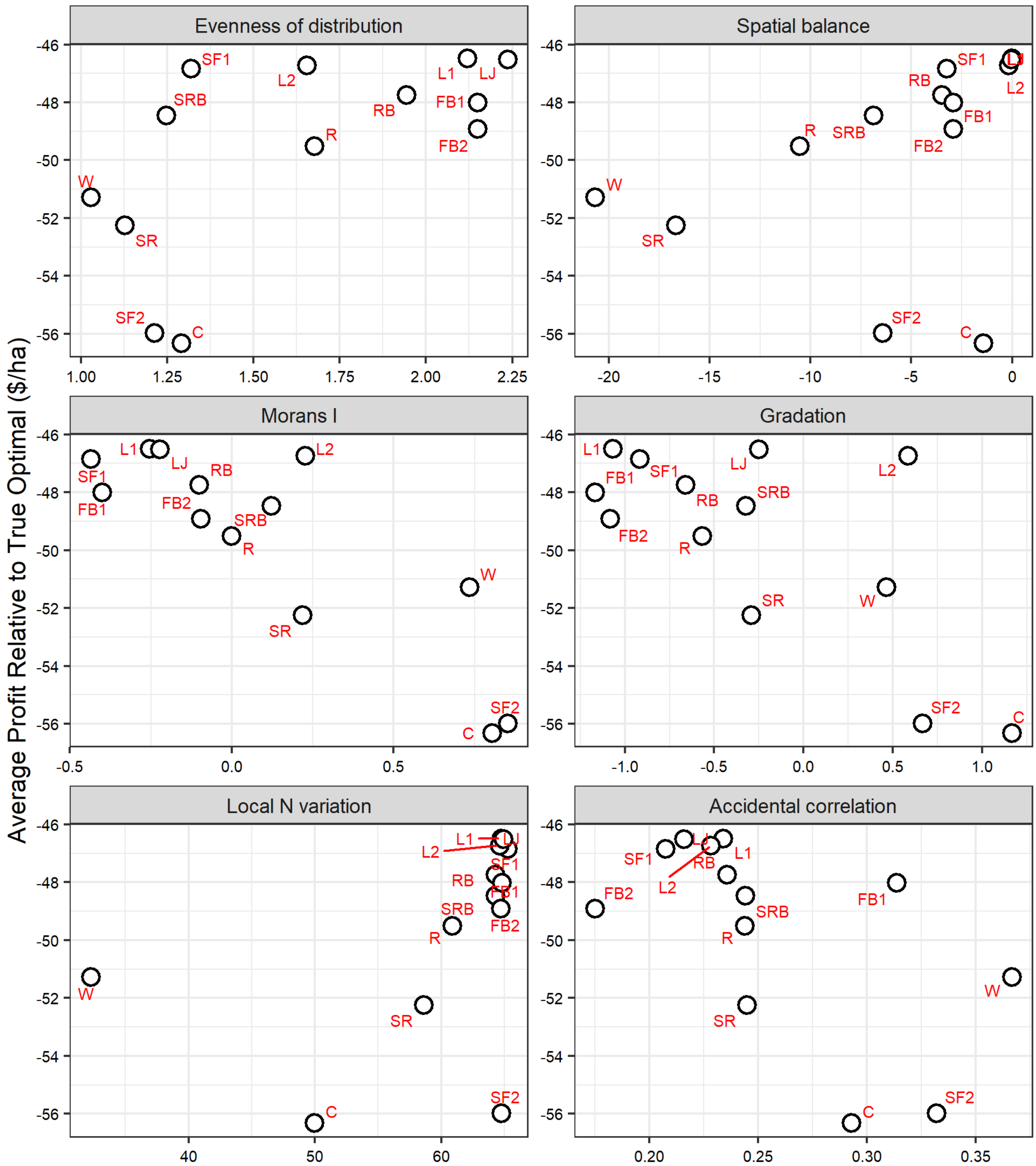

Figure 11. Scatter plots of experimental designs’ statistical “efficiency” measures and average simulated profits, from 1,000 rounds of simulation, based on a 31.3 ha field, 6.56 price ratio, and GWR estimation model.

Figure 11 presents for all thirteen designs' scatter plots showing the relationships between a trial design's profits and measures of its statistical "efficiency" measures. The relationships between the statistical efficiency measures and economic performances of trial designs were roughly consistent with expectations from the literature. In general, designs with more even distributions, better spatial balance, less spatial autocorrelation (Moran's I), less regular gradation, larger local N variation, and smaller local accidental correlation tended to have higher average profits (as well as smaller standard deviations of profits, which are not shown in Figure 11). Figure 11 was based on GWR estimation model. The relationships between statistical measures and designs' economic performances were similar for BRF and MACF models as well. Details are illustrated in Appendix Figures A.5 and A.6.

But the statistical efficiency measures were only loosely related to the economic performances of trial designs, and much about these relationships remains unexplained. **LJ** was top-ranked in most measures, but ranked only in the middle for gradation. Cascade (**C**) had very good spatial balance but low profits. **SF1** had a very uneven spatial distribution but high profits. No one measure of statistical efficiency measures by itself fully explained the economic performances of the trial designs. Different measures were also conflicting with each other. The statistical efficiency measures provide some helpful insights to guide the trial design selections, but they are not sufficient enough to fully explain the designs' economic performances.

Conclusions

The first take-away from the reported research is that the choice of trial design affects the final economic performance of OFPE. Overall, the best design was the Latin square design with a special pattern to limit N rate "jump" (**LJ**). It had the highest average profit and lowest profit variation in almost all simulation scenarios. The sizes of the economic advantages of **LJ** varied. In addition, **LJ** may limit the damage to variable application equipment that can come from abrupt, large changes in application rates.

The economic costs of using strip designs instead of gridded designs may be low in some cases. The economic performance of the high efficiency fixed-block strip design (**SF1**) was comparable to that of **LJ** in various scenarios, and could be a good alternative if only strip designs are available.

Blocking raises profits. Furthermore, the fixed block designs, by properly patternizing the spatial distribution of application rates within blocks and avoiding "clumping", may work better than randomization within blocks, particularly for strip designs.

Designs with gradual trial rate changes in every direction (**L2**, **SF2**, **C**, and **W**) were less profitable in most situations. Especially, the Cascade (**C**) and Wave (**W**) designs should be avoided.

Relative design performance depended little on prices. While design profitability varied considerably across estimation models, the profitability of the **LJ** and **SF1** was consistently high across all estimation models.

Statistical efficiency measures of trial designs roughly explained the designs' economic performances. In general, more profitable designs exhibited spatially even and balanced distributions of N rates, and "fluctuated" N rate changes were more profitable than gradual N rate changes.

The conclusions above are subject to limitations that should be addressed in future research. The thirteen trial designs examined do not exhaust the list of trial designs. Only three of the many available estimation methods were examined. No attempt was made to analyse trial design performance over multiple years involving changes in weather. Only one functional form of yield response was taken into account. Finally, the field used in the simulations typified a “flat and black” central Illinois field. It is well known that spatial heterogeneity of field characteristics increases the potential profitability of site-specific input management. Future research should examine trial design profitability on fields with more spatially heterogeneous characteristic values.

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Appendix: Statistical "Efficiency" Measures of Designs

The agronomic trial design literature stresses a number of design types with properties that tend to lend to the efficiency of estimates of yield response functions and economically optimal input application rates. We discuss three of these efficiency measures below, and also three additional measures we developed as part of the presented research.

1) Evenness of Distribution

A common opinion in the trial design literature is that a good design should have evenly distributed treatment rates over space. The left-hand panel of figure A.7 illustrates a spatially even trial design, and the right-hand panel illustrates a design in which trial rates are maximally "clumped," which is what it means for a trial design to be spatially uneven.

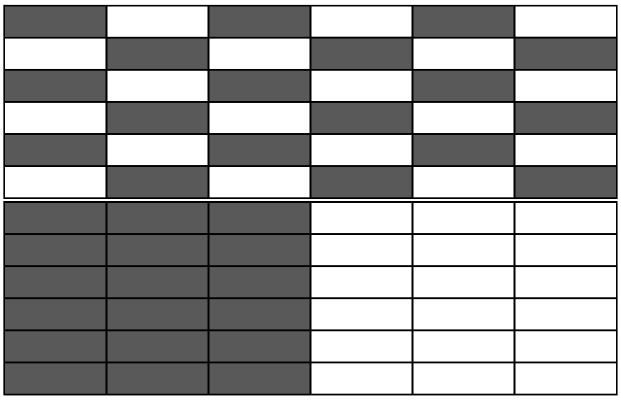

Figure A.7. Illustrations of extreme cases of spatially even and uneven trial designs.

We followed Piepho, et al. (2018) by measuring the evenness of spatial distribution by the minimum spanning tree of the Euclidean distances among plots of the same treatment.

2) Spatial Balance

Another balance measure examines the spatial distances between plots of a treatment pair. Following the definition of van Es et al. (2007), a spatially balanced design should have the distances associated with all treatment pairs as similar as possible. The distance associated with treatment pair (1, 2), for example, was calculated as the mean of distances of all possible lines connecting plots of rate 1 and plots of rate 2. The spatial balance was measured as the standard deviation of the mean distances associated with the fifteen treatment pairs of six trial rates.

3) Moran's I

Moran's I is the widely used statistic to measure data spatial autocorrelation (Moran, 1950). A high Moran's I value implies that similar treatment rates are distributed close to each other over space, which probably suggests poor evenness of distribution.

4) Gradation of N Rate Changes

Then gradation to N rate measure is original to this study. The idea is to measure whether the N rates change gradually or with wide fluctuations over space. We define a gradation index for N plot *i* as:

$$GR_i = (N_i - N_{i-1}) \times (N_{i+1} - N_i),$$

where N_{i-1} and N_{i+1} are the N rates before and after plot *i*. A positive gradation index reflects gradual changes in N rates, and a negative gradation index reflects more fluctuation in N rate changes.

5) Local Variation in N Rates

We speculated that having sufficient local spatial variation of N rates in would improve site-specific yield response estimation. Data with little local variation in N rates could reduce the accuracy or local regression estimations. In our simulated experimental fields, we define "local area" as a moving window of 6 rows and 2 columns of plots. The standard deviation of N rates within each moving window was computed, and the average standard deviation among all windows was used as the measure of local N rate variation for the field.

6) Accidental Correlation

Basic econometric theory shows that correlations between independent variable observations (N rates in this study) and the error term (yield noise in this study) biases the estimated regression coefficient. We assumed yield errors to be spatially dependent. In spatially patternized designs targeted N rates can be correlated with yield errors. The higher is the incidence of this kind of "accidental correlation", the larger will be estimation errors in the local regressions. We constructed moving windows of 6 rows and 2 columns of plots to compute the local correlation between N rates and yield errors. The average of the absolute value of the correlations across all windows was used as the measure of accidental correlation.

Figures 11 and A.5 – A.6 show correlations between the trial design statistical efficiency measures described above and the simulated profits from running the trials, analysing the data and implementing the resultant R_xs based on GWR, BRF and MACF models, respectively.

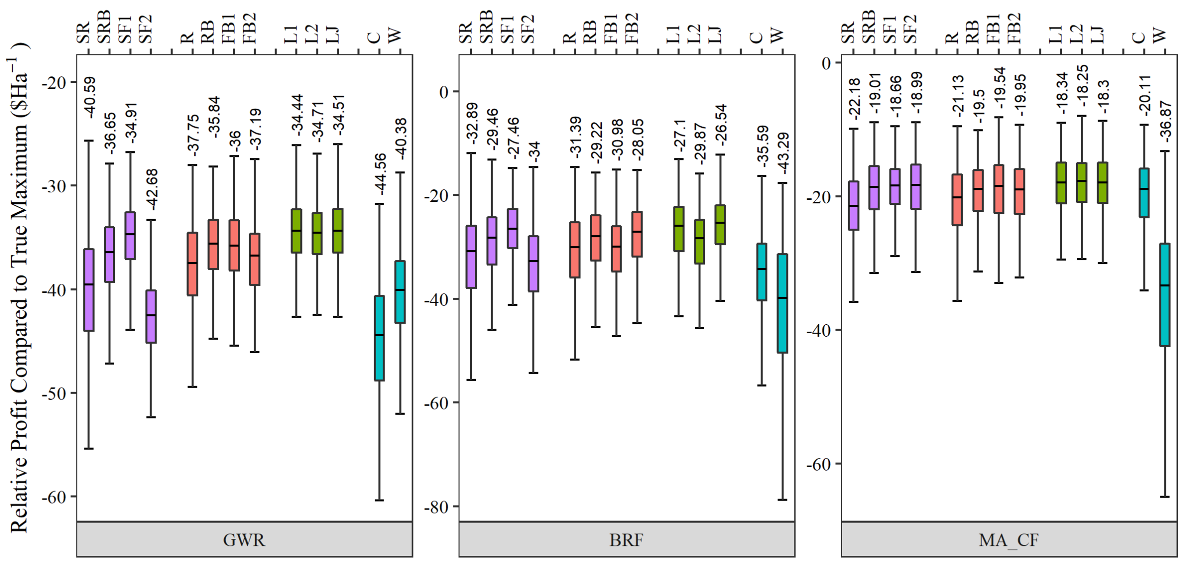

Figure A.1. Boxplots of the difference between a trial designs' profits and true maximum profits, from 1,000 rounds of simulation for each the thirteen experimental designs, based on a 4.16 price ratio.

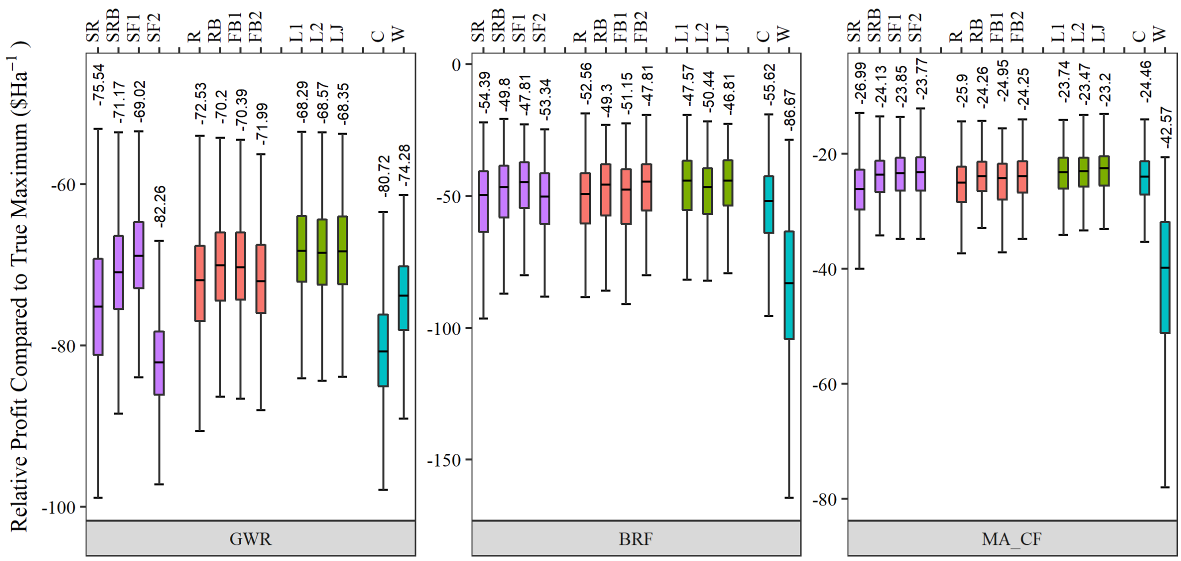

Figure A.2. Boxplots of the difference between a trial designs' profits and true maximum profits, from 1,000 rounds of simulation for each the twelve experimental designs, based on a price ratio of 10.35.

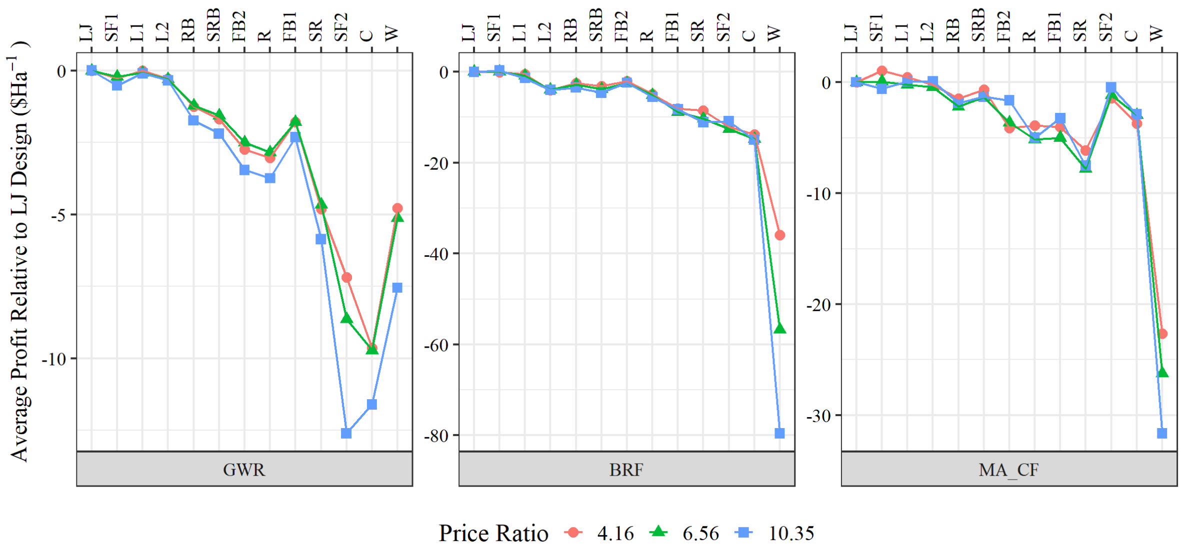

Figure A.3. Average simulated profits on the smaller experimental field, from 1,000 rounds of simulation for the twelve experimental designs, assuming price ratios of 4.16, 6.56, and 10.35. Profit values show the difference between the trail design's profits and the LJ design's profits.

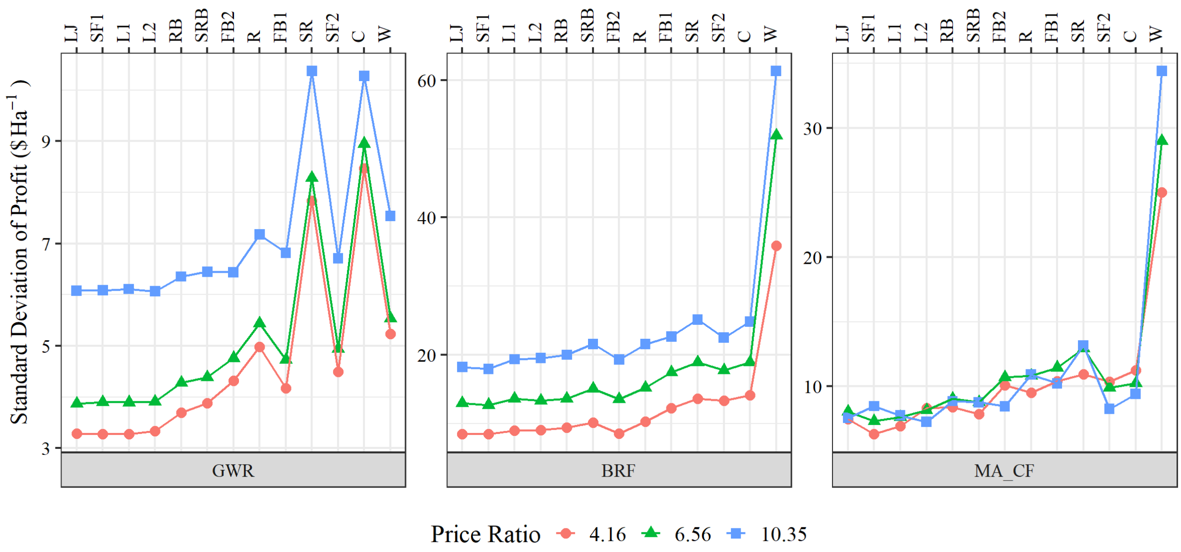

Figure A.4. Standard deviation of simulated on the smaller experimental field, from 1,000 rounds of simulation for the twelve experimental designs, assuming price ratios of 4.16, 6.56, and 10.35. Profit values show the difference between the trail design's profits and the LJ design's profits.

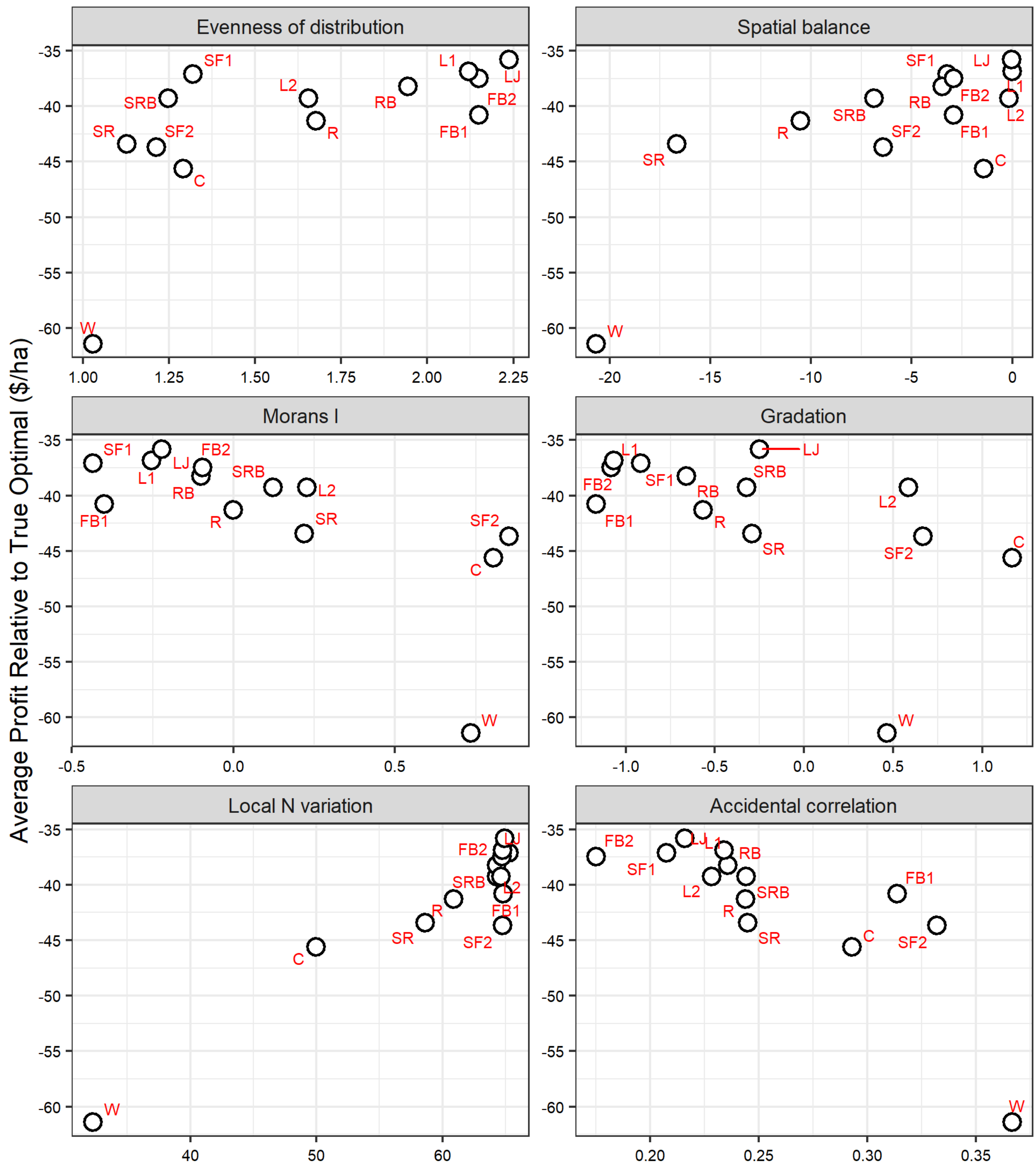

Figure A.5. Scatter plots of experimental designs' statistical "efficiency" measures and average simulated profits, from 1,000 rounds of simulation, based on a 31.3 ha field, 6.56 price ratio, and BRF estimation model.

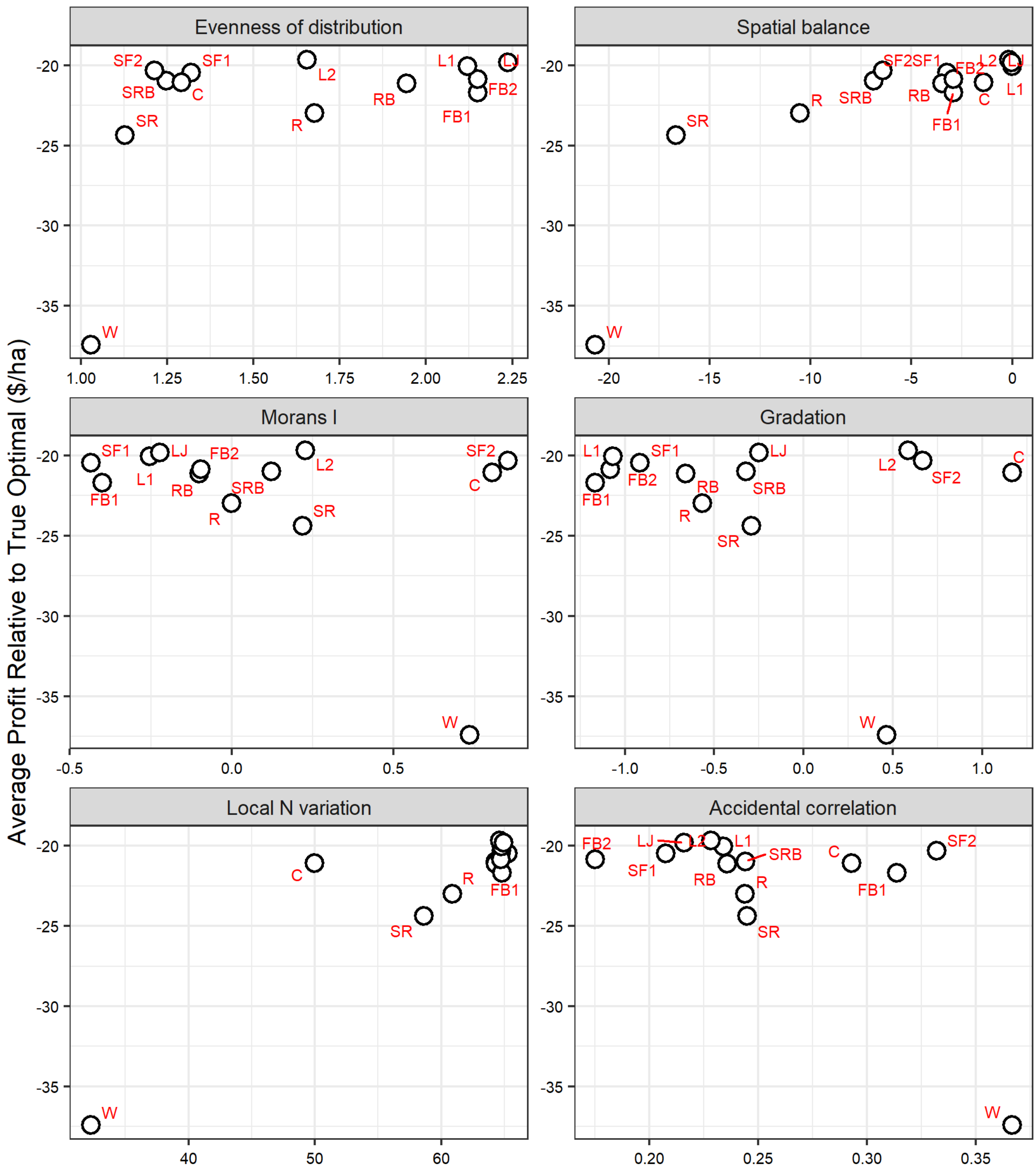

Figure A.6. Scatter plots of experimental designs' statistical "efficiency" measures and average simulated profits, from 1,000 rounds of simulation, based on a 31.3 ha field, 6.56 price ratio, and MACF estimation model.

Keynote Presentation: Readiness for robotics: adoption, ethics, regulation

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Presenter Profile

David Rose is Professor of Sustainable Agricultural Systems at Cranfield University. He runs the Change in Agriculture group, which explores how changes in policy, innovation, and technology are affecting people, production, and the planet. The group researchers aspects of agricultural transitions, including adoption of technology, farmer behaviour change, responsible innovation, policy co-design, and farming mental health.

Public perception of smart farming technologies

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Extended Abstract

Smart farming technologies have many benefits but they also come with risks. One possible concern regarding smart farming technologies is data ownership, security and privacy (Wiseman et al., 2019). For innovative food technologies, risk and benefit perceptions are an important driver of public acceptance (Bearth and Siegrist, 2016). Public acceptance can be a major barrier to technology adoption. Therefore, care must be taken to address possible concerns early on and to consider individual differences. For instance, farmers' perceptions of animal welfare in livestock breeding tend to be consistently positive, whereas consumers' perceptions tend to be negative (Te Velde et al., 2002). Despite its importance, only little research has been conducted on public acceptance of digital technologies in agriculture so far (Pfeiffer et al., 2021). One of those recently investigated the impacts of using a hoeing robot and further underlined the importance of public and consumer acceptance for the adoption of new technologies (Heitkämper et al., manuscript submitted).

Smart farming technologies cover a wide range of applications and public perception differs depending on the technology (Krampe et al., 2021). For instance, views tend to be more critical when robotics are used in the handling of living humans or animals (Pfeiffer et al., 2021). Consumers assumed, on the one hand, that precision livestock farming technologies could help reduce stress in rearing of pigs. On the other hand, they indicated that for cows, the use of precision livestock farming technologies would increase stress levels, as interactions with farmers would be reduced (Krampe et al., 2021). Pfeiffer et al. (2021) compared milking and a feeding robot for cows. They found that the milking robot was associated with more negative terms than the feeding robot. Here again, the use of a milking robot would reduce interactions between farmers and animals.

Numerous studies have focused on milking robots, whereas only a few studies have investigated other technologies. Furthermore, little is known about how factors aside from socio-demographics influence technology acceptance. As a result, our present study pursued three aims. Given the importance of public acceptance in technology adoption and the current body of literature focussing on this issue, which is rather scarce, the aim of our study was to explore consumers' perceptions of four specific digital technologies, two from crop production and two animal-related technologies.

Data were collected using an online survey in 2021. The survey was conducted in German and sent to a convenience sample (via direct invitations or through social media). The survey was further sent to an online panel of individuals who indicated in previous studies to be willing to participate in online studies again. Participants were presented with pictures and short descriptions for four smart farming technologies, two each from crop and livestock farming.

In a first step, they were asked to note their first association, a word or picture that came to their minds. Next, they provided hedonic ratings for the associations provided earlier on a scale from 0 (very negative) to 100 (very positive). As an incentive for participation, participants were offered a short summary of the study results upon completion of data analysis. The final sample consisted of 287 participants who completed the survey. The sample's mean age was 49 years with 43% female participants. Education levels were quite high with 30% of participants indicating that they had a university degree.

As examples of technologies in crop farming, we used spray drones and hoeing robots. On average, participants gave positive hedonic ratings for spray drones (M = 65.2, SD = 34.0). Participants mostly worried about the noise. Similarly, participants named positive associations for hoeing robots (M = 65.7, SD = 30.8). Major negative points were the costs and the effect the robot might have on the soil, such as soil compaction. This is an interesting finding as soil compaction has gained a lot of public attention. However, for hoeing robots, the experts' perception is that it can reduce soil compaction as compared with traditional farming methods (Gerhards et al., 2022). We further noticed that social impacts (i.e., labour facilitation) were mentioned for the hoeing robot but not for the spray drone.

As examples of technologies in livestock farming, we used virtual fences and milking robots. For virtual fences, participants' hedonic ratings were on average negative (M = 34.2, SD = 30.4). The most frequently mentioned associations were related to animal welfare and various negative words. A group of 23 participants named positive words, expressing their interest in or support of this technology. Clearly, a major issue, aside from concerns regarding animal welfare, was the fact that participants did not see the benefit of this technology. The category useless was among the most popular associations for virtual fences, summarising responses that indicated that the technology does not make sense, has no use, or participants do not see the benefit. Although this might be partly due to the description we provided, it still serves as a strong indication that clear communication focussing on benefits is needed if this technology is to be used more widely. Similar effects were reported for gene technology, where the absence of consumer benefits led to more perceived risks and moral concerns, calling the technology into question (Gaskell, 2000). Therefore, as suggested elsewhere (Stampa et al., 2020), communication with the general public should not focus on the technology but on its benefits and make sure the public does not oppose it.

For milking robots, participants' overall hedonic ratings were positive (M = 60.7, SD = 32.5). It seems that this technology is quite well-known, as 10 participants named associations which indicated that they already knew about it or that it is an established technology. The most frequently mentioned point of criticism regarding this technology is the decreased relationship between animals and humans.

Overall, we found that participants gave higher hedonic ratings for the two technologies in the domain of plant production (i.e. spray drones and hoeing robots) as compared with the technologies in the domain of animal production (i.e. virtual fences and milking robots). This is in line with results from the study by (Pfeiffer et al., 2021), who found that the commonly mentioned categories for animal-related technologies were more negative than those for plant-related technologies. However, whereas they found that three out of the five most frequently mentioned associations for the milking robot were negatively associated, we only found one negative and one neutral category among the most frequent five. Among the five most mentioned associations were also three positive associations, including labour facilitation for farmers and the self-determination of cows.

A common category that was frequently mentioned and positively connoted for all four technologies is Future and Progress. Attributes such as innovative, ingenious, futuristic or modern were important for all four technologies. We see this as an indication of the public's general interest in or fascination with smart farming technologies. With regard to current challenges, that is, climate change or scarcity of resources, this is a great opportunity to tackle the challenges while counting on public support.

An important issue mentioned that was exclusive to the animal-related technologies is animal welfare. For virtual fences, it was the most frequently mentioned with a negative hedonic rating and for milking robots, and it was the second most frequently mentioned with, on average, a neutral hedonic rating. Both technology communication and communication need to make sure they address and ensure animal welfare to receive public support.

In sum, our results provide initial and important insights into the public's acceptance of the digital transformation in Swiss agriculture, which appears to be very positive. Overall, we found that consumers generally have positive associations towards digital technologies in agriculture. Importantly, general perceptions of digital technologies were further identified as a predictor for the perceptions of specific technologies, which offers an interesting starting point for efforts aiming to increase public acceptance of specific technologies.

Keywords

Smart farming technologies, public acceptance, crop and livestock farming, spontaneous associations, hedonic rating

Presenter Profile

Jeanine Ammann was born 1989 in Switzerland. She studied food science at ETH Zurich and worked in various industries (bakery, laboratory). After a few years of work experience, she returned to ETH Zurich in 2016 to earn a doctoral degree in consumer behaviour, investigating food disgust sensitivity and raising her profile as social scientist. Following the doctorate, she worked as postdoctoral researcher and lecturer in the consumer behaviour group at ETH Zurich before starting a postdoctoral position at Agroscope in 2020, where she currently works as researcher and deputy group leader.

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The role of Artificial Intelligence (AI) in agriculture and its impact on economy

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Abstract

In terms of the economy, agriculture plays a significant role. In agriculture, automation has become a major concern and a hot topic around the world. Food and employment demand are rising as a result of a rapidly expanding population. Using the new methods, billions of people were able to meet their dietary needs while also gaining employment opportunities. Farming has undergone an enormous change thanks to artificial intelligence. Crop yields have been protected by this technology from a variety of threats, including climate change, population growth, labour shortages, and concerns about global food security. Weeding, spraying, and irrigation are just a few of the many uses for artificial intelligence in agriculture that this paper examines in detail, with the help of sensors and other tools built into machine and drones. Water, pesticide, herbicide, and soil fertility use, as well as labour use, are all reduced thanks to these new technologies, which boost output while also improving product quality. Robots and drones are being used for weeding in agriculture, and this paper compiles the findings of numerous researchers to give readers an overview of the current state of automation in agriculture. Soil water sensing techniques and two automated weeding methods are discussed. It is discussed in this paper how drones can be used for spraying and crop monitoring, as well as the various methods they can employ.

Keywords

artificial intelligence, agriculture, economy, technological farming, rural areas

Presenter Profiles

An Associate Professor in Warsaw School of Economics, Poland. She deals with the issues of sustainable development in a very broad sense. In the area of her research interests there is both sustainable development in the field of renewable energy and issues in the area of finances, including finance technology, in which innovative financial tools - in the strict sense, i.e. cryptocurrencies and in the broad sense, i.e. to influence a number of economy sectors, i.e. agriculture, industry, services. She is giving lectures at different University all over the World- University of Santiago de Compostela (Spain), University of Alicante (Spain), University del Pacifico in Lima (Peru), Strathmore University in Nairobii (Kenya).

AI's impact on farming

There is a wide range of applications for AI-based technology in all industries, including agriculture, which covers crop production and irrigation as well as soil content and crop monitoring. Agricultural robots are a high-value use of AI in the aforementioned field. AI has the ability to give a much-needed solution to the agriculture dilemma, which is exacerbated by the rising global population (Abdullahi and Sheriff, 2015). An increase in the amount of output and the quality of the product has been achieved thanks to AI-based technology, which has led to a speedier time to market. Farmers will utilize 75 million linked devices in 2020. Approximately 4.1 million data points will be generated by an average farm per day by 2050, according to forecasts. Robots and artificial intelligence (AI) have made a variety of contributions to farming, including:

Recognizing and perceiving images

In recent years, interest in autonomous unmanned aerial vehicles (UAVs) and its applications, such as recognition and surveillance, human body detection and geolocation, search and rescue, and forest fire detection, has increased. Aerial drones, also known as unmanned aerial vehicles (UAVs), are growing in popularity due to their numerous applications and impressive imaging capabilities, which include everything from delivery to photography. They can be controlled via a remote controller, and their dexterity in the air makes them ideal for a wide range of tasks.

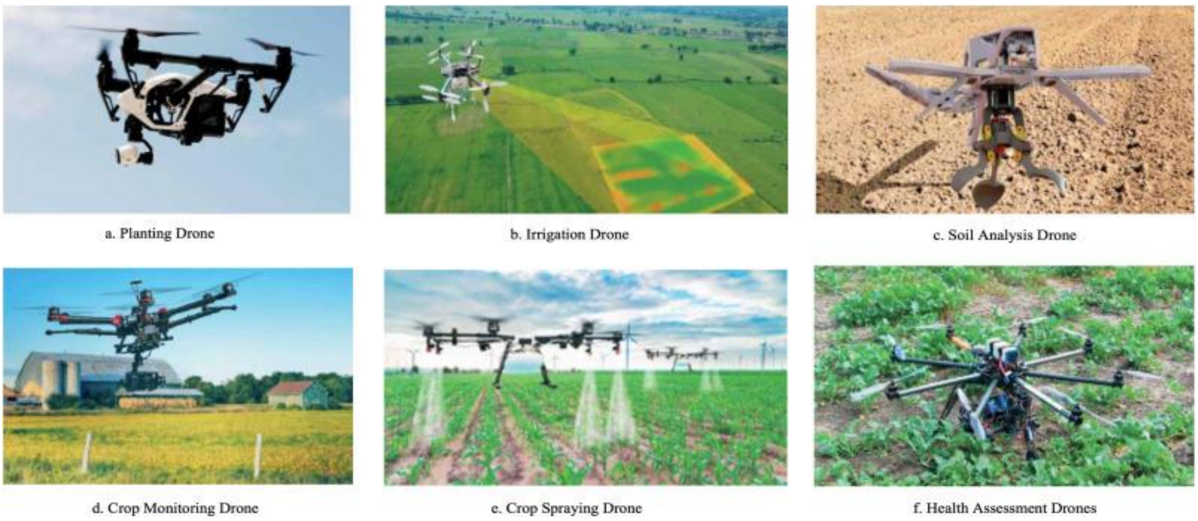

Figure 1: Artificial intelligence role in agriculture. Source: Ahirwar et al. (2019).

Human capital and skills

Many unclear concerns, as well as a wiser irrigation system, may be solved with the help of artificial intelligence, which gathers data from government and public websites, analyses it, and provides farmers with solutions. It is likely that farming in the near future will combine technical and biological talents, resulting in greater quality for all farmers as well as reduced losses and workloads thanks to AI. Approximately two-thirds of humanity will be residing in urban areas by the year 2050, making it imperative that farmers be relieved of their current duties. The use of artificial intelligence (AI) in agriculture can result in automated operations, decreased risks, and easier and more effective farming.

Maximize the amount of work done

Plant performance peaks are determined by the types of seeds used and the quality of the seeds themselves. Crop selection and improved hybrid seed options have been made possible by new technology. Because of the information acquired, plant diseases may be less common. Market trends, annual results, and consumer demands can all be taken into account by farmers to increase crop returns to the highest possible level (Aitkenhead et al., 2003).

Farmer-friendly chatbots

They're just conversational virtual assistants that handle customer service tasks. Farmers have used the AI facility to assist them in receiving answers to their unanswered questions, to give advice and to provide various recommendations. These facilities are primarily for retail, travel or media (Albaji et al., 2010).

Farming with robots

Agri-Food is one of the many industries that will benefit from the introduction of Robotics and Autonomous Systems (RAS). From primary farming to retail, the UK Agri-Food chain generates more than £108 billion a year and employs more than 3.7 million people in a truly global industry that generated £20 billion in exports in 2016. Agricultural production and management have benefited greatly from robotics. A lack of efficiency in conventional farming machinery has prompted researchers to focus on the development of autonomous agricultural tools. On both small and large-scale productions, this technology has proven to be an effective replacement for human labour. Robotics have had a huge impact on productivity in this industry.

Figure 2: Farming through AI machinery. Source: Anand et al. (2015).

Wetlands and irrigation systems

The agriculture sector consumes over 85% of the world's freshwater supply. Moreover, as the global population expands and food consumption rises, this percentage will continue to rise at an even higher rate. As a result, better irrigation methods are required in order to make optimum use of water. Automated irrigation scheduling methods have replaced manual irrigation based on soil water measurements. The evapotranspiration of plants is affected by a range of environmental elements, such as wind speed, sun radiation, and even crop parameters, such as plant density or the presence of a pest, and an autonomous irrigation system was developed to account for this.

The technique of smart irrigation has been created to boost production without the need for large numbers of people by monitoring water levels, soil temperature, nutrient content, and projections of weather conditions. The irrigation pump is controlled by a microprocessor. In agriculture, M2M technology, or "machine-to-machine" technology, has been created in order to facilitate communication and data sharing between and among all of the nodes of the agricultural field through a central network. An automatic robotic model was developed to measure the humidity and temperature of the gadgets in use. At regular intervals, the Arduino's microcontroller (which is coupled to edge-level hardware) processes analogue data and converts it to digital. When the Raspberry Pi 3 gets a signal, which is pre-loaded with the KNN algorithm, it transmits it to the Arduino. It will also be used to update and store sensor data, in addition to providing water (Arvind et al., 2017). Arduino-based irrigation systems have also been developed to save time and effort in irrigating crops. Sensors use a number of technologies to figure out how much moisture is in the soil. It is tucked away among the roots of the plants. For irrigation, the moisture content of the soil is measured using the sensors and the data is sent to the controller. Soil moisture sensors can also considerably reduce water use. It's possible to set a threshold depending on the soil's field capacity and use moisture sensors to water only when needed. When the timer goes off as scheduled, sensors assess the zone's moisture content and only enable watering if it falls below a predetermined threshold. Suspended cycle irrigation, on the other hand, necessitates a longer irrigation period than water-on-demand. There must be a start and end date for each zone.

Irrigation robots cannot function properly without sensors. Irrigation may be controlled in several fields with a single sensor. You can also set up numerous sensors to water different parts of the property. In the first situation where one sensor is used for irrigating different zones, the sensor is placed in the driest section of the field to ensure enough irrigation. Root zone sensors are the best spot to put them, because that's exactly where the plants acquire all their water and nutrients (and there should be no air gaps around the sensors). This will help to ensure that the crops receive adequate amounts of moisture (Bak and Jakobsen, 2004). Later, the SMS controller and sensor must be linked. It is only when the sensor detects movement that the control system takes over. Afterward, the soil water threshold has to be determined. A day of watering is required to soak the sensor once it has been buried. A timed irrigation sensor is configured to operate when the water level reaches a specified level, as previously stated.

Weeding:

Thomas K. Pavlychenko, an early pioneer of weed science in the United States, check out "A History of Weed Science in the United States." After conducting extensive research, he found that weeds were the strongest competitors for water because their roots in the soil overlap to collect water and nutrients. In order to create a pound of dry matter, a plant need the same amount of water as its aerial components. Three times as much water is needed to mature ragweed (Ambrosia artemisiifol ia) as corn or wild mustard (Brassica kaber var. pinnatifida). The dry matter output per acre of a plant is divided by the water need of the plant to arrive at the acre's total water requirement. Light is also essential to plant growth. It is common for tall weeds to block sunlight from reaching nearby plants. For shade-tolerant plants, consider Arkansas rose or field bindweed (also known as milkweed spuroe) (also known as common milkweed spotted spuroe). Over $11 billion in annual agricultural productivity is stolen from India by weeds, according to a report by the Indian Council for Agricultural Research (ICAR). In addition to taking up valuable growing area, these weeds can impair the health of other crops if they aren't eradicated (Bakker et al., 2006).

It was built and created using heredity calculation for weed detection using Hue-Saturation-Intensity shading space for weed detection in open air fields (GAHSI). These mosaicked settings allowed us to determine whether or not GAHSI could be utilised to locate shade space locations or zones when these two borders are exhibited at the same time. This group's appearance following the GAHSI was proof of the location's existence and detachability. We were able to estimate the GAHSI execution by comparing the GAHSI-portioned image to a hand-sectioned reference image. The GAHSI was on par with it in this way.

An automated weed management system must first discriminate between crops and weeds in order to be effective. A method was used to tell carrot seedlings apart from ryegrass seedlings. Leaf morphology is used. With a success rate ranging from 52% to 75%, leaf size variation can be utilized to identify plants from weeds. A novel way of weeding was introduced using digital photography. This concept was implemented using a self-organizing neural network. NN-based technology was found to already exist, allowing for the accurate detection of 75% of the changes between species, however this method failed to produce the appropriate results required for commercial use (Bendig and Bareth, 2012).

A chemical-based

Herbicides must be sprayed on specific areas, and those areas are defined by the first two conditions listed above. There are some areas that do not require spraying because they have a low number of weeds. Weeding requires this step. To get rid of weeds, you don't need to spray every part of the weeds, but you do need to spray enough areas so that the weeds are absorbed by other parts and ultimately destroyed. However, if the sprayed areas are too small, the weeds may not be destroyed, so it's important to be cautious.

Pulse high voltage discharge (PHD)

Non-chemical weeding methods are becoming increasingly popular as environmental and economic concerns about the use of chemicals grow. Non-chemical weed management has also seen a rise in popularity as a result of the growing interest in organic farming. Mechanical, electrical, and biological weed control methods have been studied. In the United States, pulse high voltage discharge (PHVD) is a popular non-chemical weed management approach. It only takes one 15-kV spark to eliminate these tiny weeds (their stems are about 2 mm in diameter and they stand about 5 cm tall). It is possible to eliminate large weeds with a 20 Hz charge (their diameter is 10–15 mm and their height is 80–120 cm). As a result of the spark charges, the movement of waiters to various locations is disrupted. A few days after the spark, the weeds begin to wilt. Rather than using nozzles, spark discharging devices are used in place of the chemicals in this method. The technology is set up to only apply the spark to regions where weeds are detected. Once weed sites have been discovered, the system for spark discharge selects weed points, which represent weed locations. This method, like the previous chemical method, has some conditions that must be met. The following are the conditions:

- Pixel coordinates in images are averaged and this is used to determine the centre of the region.
- This is where the weeding spark discharge is applied.
- A weed is considered destroyed if it receives the spark discharge.
- Weed destruction potential is determined by establishing the first two conditions and then determining where to discharge spars in the fields.

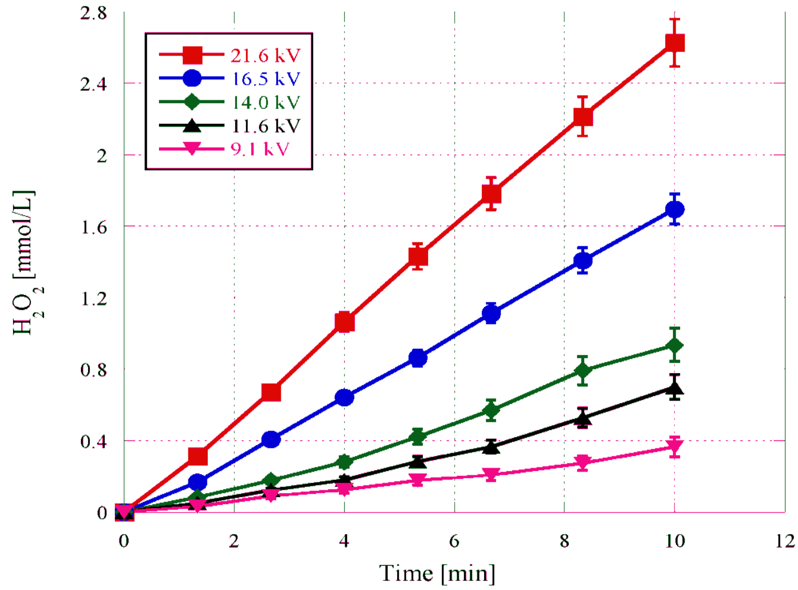

Figure 3: Role of pulse high voltage discharge in AI agriculture. Source: Talaviya et al. (2020).

The use of unmanned aerial vehicles in agriculture

Images captured and processed by UAVs are having a major impact on agriculture thanks to remote sensing techniques. It appears that the rural business has enthusiastically embraced ramble innovation, and is using these propelled instruments to change current agricultural practices. An ongoing PwC study estimates that automation-fueled arrangements in all relevant industries could be worth over USD 127 billion. These sensors are comparable to a standard camera in that they capture clear images, but a multispectral sensor expands the procedure's usefulness by allowing farmers to see things that are not visible in the visible range, such as soil moisture content and plant health monitoring. These might be useful in overcoming the various obstacles that agrarian production faces. Wireless Sensor Networks (WSNs) are used to develop the UAS (WSN). As a result of the WSN's data, Synthetic substances sprayed by the UAS can be more precisely targeted thanks to the UAS's precision spraying capabilities. Due to the frequent changes in ecological conditions, it is almost probable that the control circle must respond as quickly as feasible. The rapprochement of the WSN could be a positive development. Uses in precision agriculture include soil and field analyses, crop height calculations, pesticide application, and more. As long as you stick to the most crucial features like weight, range, payload, and configuration you may be more flexible with your hardware implementations. In a research project, the use of unmanned aerial vehicles (UAVs) is explored, as well as its advantages and disadvantages. More than 250 UAV models are studied and summarized in order to find the best one for agriculture (Bhaskaranand and Gibson, 2011).

Spraying crops

As a result of sensor and microcontroller developments, the travel of unmanned aerial vehicles and their autonomous behaviour are facilitated by UAVS. This isn't a new phenomenon; farmers have been using drones to spray crops for a long time, and they've proven to be extremely effective in foggy weather and in fields with tall crops, such as maize. A major advantage over high-resolution satellite airborne sensors is widely acknowledged as well. In 1987, a microcomputer-based control framework was retrofitted onto an air-carrier plantation sprayer by Giles et al. Ultrasonic range transducers were used to estimate foliage volume, and the sprayer's 3-nozzle manifolds on either side were regulated by control calculations depending on the amount of spray deposited. Using drones to spray synthetic compounds on crops, a control circle was formed with the use of drones in horticulture. These drones administered synthetic substances to the crops in the field under the guidance of remote sensor networks. Drones were only allowed to spray synthetic compounds in specific regions with the help of remote sensors (Birrell and Borgelt, 1996). It was possible to create an autonomous helicopter sprayer with a small spraying capacity. A helicopter with a maximum payload capacity of 22.7 kg and a rotor diameter of 3 m was employed in this study. There was a 45-minute use of one gallon of gas. This technology and its systematic results can be used to develop UAV flying application frameworks with larger VMD droplet sizes and higher target rates.

An energy sprayer that uses hydraulics

The Hydraulic Energy Sprayer can pressurize the sprayed substance using either one of two processes. It is possible to see the gaseous tension above the shower material by using either a positive uprooting syphon or a vacuum device. This pressurized fluid is released through the splash spout. The syphon is responsible for supplying energy to move the material to the plant. Water is the source of power. There is an overwhelming majority of beads that stretch 200–400 meters from the sprayer's nozzle (Blasco et al., 2002). The inclusion and interaction with the insect or illness is more uniform since the beads are framed in a fog or haze. Because of this, even if the muskiness is modest, little beads are unlikely to reach their desired destination. This is a water-powered sprayer's component list: tank, syphon with initiator, weight measuring device, control valve, help valves and valves for managing the spray pattern and the source of power for driving the spray pattern.

This sprayer uses a gaseous energy source

The Gaseous Energy Sprayer's high-speed air stream is created by blowers. An air stream is guided down the pipe toward its conclusion by a diffuser plate, allowing spray liquid to flow. To get to where it needs to go, a liquid or residue must be carried through the air.

Sprayer with centrifugal energy

A fast-turning device in the Centrifugal Energy Sprayer can be a level, a concave or flat plate, a wire mesh cage or bucket, a piercing chamber, or a brush. Water from the atomizer exits the outer edges of the atomizer and is atomized by diffusive power as it passes through the focal point of this device's shower liquid. It is not necessary for a sprayer to have a fan in order to distribute droplets (Bond and Grundy, 2001).

Sprayer that uses kinetic energy as a propellant

Gravity directs the spray liquid to a vibrating or swaying spout, creating a fan-like spray pattern with the Kinetic Energy Sprayer. This equipment's main duty is to spray herbicides (Chang and Lin, 2018).

Impact of AI on agriculture in rural areas

The meaning of neediness as featured before is a diverse peculiarity at the end of the day neediness is complex. It shows itself in absence of pay, absence of schooling and now and again absence of social help and even food weakness. This for the most part influences rustic regions where the vast majority of the destitute individual's dwell. As indicated by the World Bank, farming is the wellspring of work in regions where destitution is more common. Computer based intelligence applications can address the different difficulties that are looked by individuals at the lower part of the pay conveyance particularly the base 40%. Despite the fact that a large portion of destitute individuals can't buy AI-empowered gear, it has been contended that these individuals can straightforwardly profit from AI through AI administration arrangements on their cell phones (Choudhary et al., 2019). Nuru, an artificial intelligence application that was used in Kenya, Mozambique, and Tanzania, is a good example of how this technology could be used in the developing world. Ranchers used this app to document leaf damage in images taken by specialists sent to assist in spotting one of East Africa's most elusive pests, which has been threatening homesteads' income and food security for years. As a result of artificial intelligence, cell phone data can be a powerful indicator of wealth, education, and even health status. Microloans, personalized mentoring, and seeking health and medication advice can all be delivered through mobile applications using this technology. As a primary use of AI applications, AI discourse acknowledgment and discourse to message features are used to help the most disadvantaged persons gain access to message-based apps. In most country regions that are a long way from the metropolitan regions, AI through picture acknowledgment can be utilized in the evaluation of microinsurance cases of ranchers.

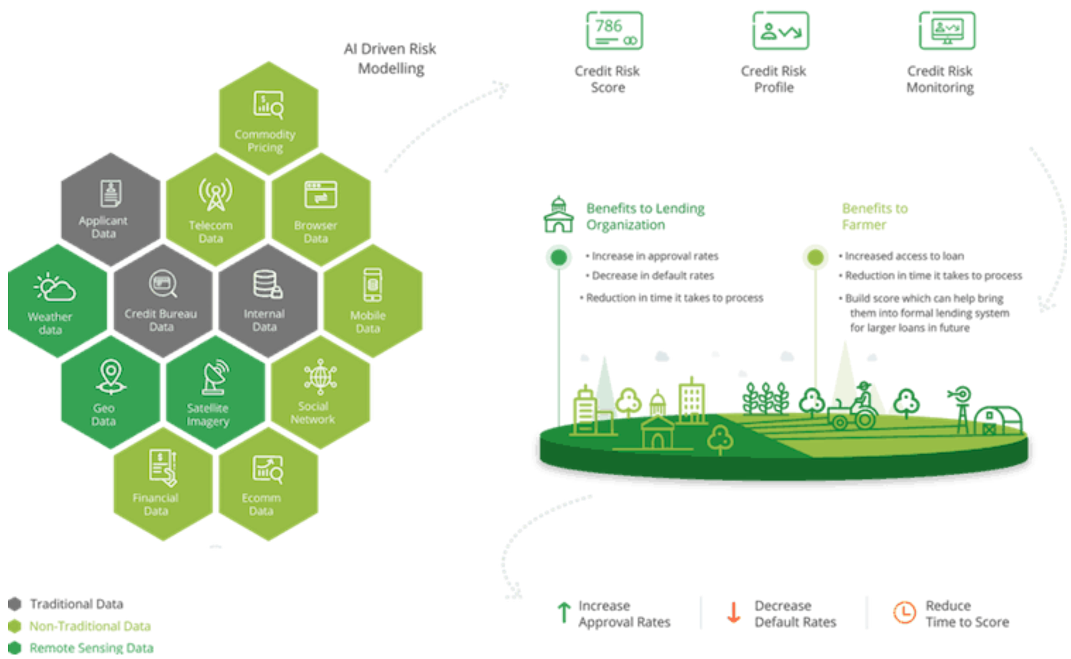

Figure 4: AI role in agriculture in rural areas. Source: Chung et al. (2016).

Furthermore, become self-sufficient in terms of nutrition. In 2020, the Decentralized AI Alliance declared that AI can alleviate poverty by improving soil development for growing crops and animal husbandry as a means of providing food and other essentials. Robots can now aid farmers in harvesting crops and predict the best methods for farmers to grow diverse harvests through the use of AI technologies. Utilizing mechanical technology, AI is turning into a significant variable in tackling widespread starvation Google and Stanford University's Sustainability what's more, Artificial Intelligence Lab are making progress in this area. These organizations are working with AI programs in agribusiness that are doing a lot of work on growing, helping to identify sicknesses, predicting harvest yields, and identifying locations at risk of food shortage (Cillis et al., 2018). One model where AI is being applied is through Farm View program made by specialists from Carnegie Mellon University (CMU) to assist ranchers with developing more food utilizing similar number of harvests. This work is being applied to concoct fast answers for the basic issue of paid ascent in populace. It is assessed that continuously 2050, roughly 9.8 billion individuals will live in the world, and this will increment food shortage making this point extremely basic. Be that as it may, the accessibility of AI will assist with further developing cultivating techniques detecting and advanced mechanics innovations to further develop plant reproducing and crop the executives. Specialists are caught up with gathering a great deal of data utilizing robots, robots, and fixed sensors to expand yields of dry spell and hotness safe harvests that can flourish in starvation-stricken countries. Through AI innovation analysts and AI advances information is dissected to figure out what variables yield more sorghum. One more illustration of where AI is helping a ton in agribusiness is through industry.

PlantMD. Shaza Mehdi and Nile Ravanell, two Georgia high school students, created PlantMD as a class project. A rancher can use this software to find out if his plants are sick thanks to the features it offers. Google's TensorFlow AI library was used to build this application. At Penn State, a group called Plant Village was working on an application named Nuru, which was affecting the PlantMD application that they were working on. To combat infection and irritating powerlessness in cassava, one of the yields that feed a major fraction of a billion Africans every day, the application (Nuru) was developed as before mentioned. Ranchers experienced issues in examining and dealing with each yield (Costa et al., 2012). Because of the accessibility of AI, AI is currently used to increment productivity during the time spent illness and vermin control. "An AI model was prepared utilizing large number of characterized cassava pictures and the model was transformed into an application where ranchers can send pictures of their yield and get data which empowers them to distinguish sicknesses with choices accessible to deal with the illnesses". Thusly, AI is helping African agribusiness to be reasonable which can assist farming with taking care of individuals. Additionally, Stanford University is using AI to comprehend and foresee crop yields in soybeans. Moreover, It is accepted that AI can likewise help with finding places in creating and immature countries with food instability issues through satellite innovation. The following area is framing the way that AI can help in the instruction area (De Oca et al., 2018).

This large number of advancements are upheld by different researchers who explored the significance of AI in the development and improvement of economies, for example, the total populace is supposed to increment to 2 billion of every 2050, while the arable region is supposed to develop by just 5%. Accordingly, shrewd and effective cultivating methods fuelled by AI and AI are important to further develop farming efficiency. The use of AI has been clear in the rural area. To address some of the issues affecting the horticultural sector and increase yields, AI plays an important role. When it comes to things like ensuring that the soil is properly treated, disease and irritant invasion control is in place, ensuring that large information needs are met, and reducing the information gap between ranchers and technology, there are a number of options (Dela Cruz et al., 2017).

AI impact on education

Man-made intelligence can help with raising the degrees of schooling for unfortunate youngsters the different strategies which incorporate adjusted learning procedures utilizing PC calculations to energize communication with the student as well as thinking of training that is tailor-made for the requirements of every student. Utilizing Computer based intelligence, it is exceptionally conceivable to find the particular advancing necessities of every student and have the option to fulfil these prerequisites utilizing different strategies for learning. In other exceptional conditions, insightful visit loads up are utilized as coaches breaking the cash hindrance to training to students who come from unfortunate regions which will assist with addressing access issues lastly have the option to address imbalance simultaneously (Dukes and Cardenas-Lailhacar, 2009).

During the COVID-19 social separating, the use of Industry 4.0 technology helped students have the opportunity to continue their education even during the lockdown. The concentrate too observed that innovation could build admittance to training particularly online instruction where space is anything but a restricting component. One of the training projects where Artificial Intelligence (AI) is helping to improve education in Kenya, Ghana, and Côte d'Ivoire through the Eneza Education social initiative. In this regard, AI is playing a significant role in the success of value education. This also gives teachers the ability to provide thorough and even-handed training, allowing them to unlock students' hitherto untapped capacity for learning. the importance of AI in education amid the COVID-19 pandemic lockdown. Despite the fact that they argued that it would be difficult for AI to take over school administration, AI will play a major role in instruction during the COVID-19 pandemic.

AI and Digital Financial consideration

Advanced monetary incorporation is seen as an approach to contacting the families who are not monetarily dynamic, that is the individuals who can't appreciate formal monetary administrations that are intended to address their issues. Women, young people, and the impoverished, particularly those still living in rural areas, are excluded from the formal financial system. Conventional ways of alleviating poverty and increasing social well-being are being disrupted as AI alters the cost of access to goods and services, how data is generated, and how products are created. The difficulties related with improvement are progressively becoming entwined with innovation where the objectives of finishing neediness and helping shared thriving are turning out to be fundamentally subject to outfitting the force of advancements like AI and simultaneously searching for ways of limiting the dangers related with these advances.

It has been laid out that in developing business sectors nations are starting to utilize essential AI to concoct answers for basic difficulties of improvement, particularly in the arrangement of monetary administrations to underserved and unserved populaces (Garre and Harish, 2018)The enormous advancement in fundamental AI calculations and the development in the quantity of innovation clients made it workable for developing business sectors to utilize AI arrangements like credit scoring and designated publicizing. A few early instances of AI being conveyed in monetary business sectors remember M-Kajy in Madagascar, M-Shwari in East

Africa, and Ant Financial in East Asia. By employing artificial intelligence (AI) techniques, M-Shwari has created an estimate of the likelihood of potential borrowers failing to repay their loans, which has made it possible for 21 million Kenyans to receive small loans before the year ends. AI is driving advances in monetary administrations by relying on modern information such as mobile phone call records, portable cash exchanges information, instant messaging, and address books, all of which are based on modern information.

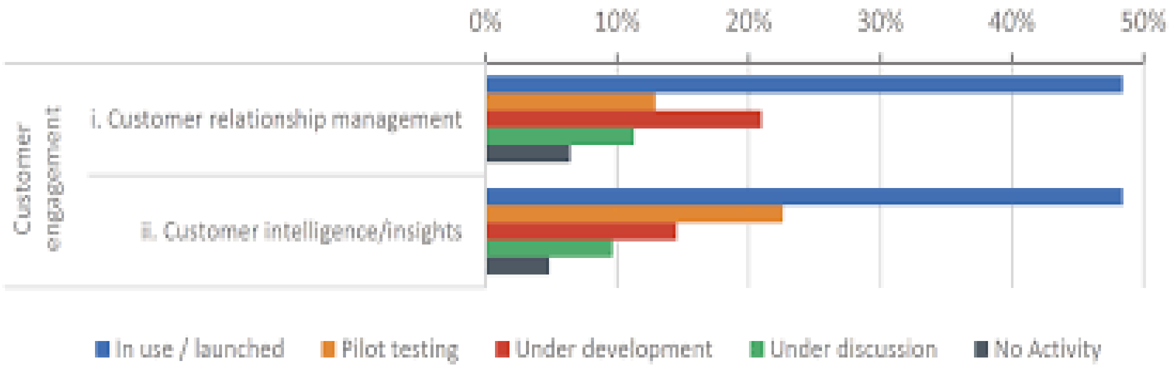

Figure 5: AI and financial sectors. Source: Pedersen and Blackmore (2008).

AI also contributes to lessening the data asymmetry in situations when borrowers, like first-time borrowers and those without a bank account, require a financial history. Furthermore, AI is improving monetary administrations by automating credit rating, a cycle previously assigned to human resources in more traditional monetary foundations. Artificial Intelligence (AI) can be used to analyses a lot of cell phone data in order to provide clients in emerging economies with fast financial analyses. Once the client has been offered an advance by consuming record information, the scoring calculation is further developed. Offering microloans to customers in countries like Kenya, Nigeria, India, and Mexico who do not have bank accounts is one way that Branch One of the fintech companies is using this method to microloans.

Challenges and scope for the future

More than a few major issues have been addressed by agriculture in recent years, including the lack of irrigation system, changes in temperature, and a greater density of groundwater. The reception of various cognitive solutions has a significant impact on the future of cultivating. An extensive amount of work remains, although a few products are already on the market. It's early days for farming when it comes to adopting autonomous decision-making and predictive solutions to deal with the real-world difficulties faced by farmers. For artificial intelligence (AI) to reach its full potential in agriculture, more robust applications are needed. It can make real-time decisions and use a suitable framework/platform efficiently if this is the case, and it will be able to react to rapidly changing environmental conditions. The high price of commercially available cognitive farming systems should also be taken into account. Solutions must become more affordable to make technology more accessible to a broader range of people. The solutions would be more accessible to farmers if they were built on open source platforms, which would lower their cost of entry (Pharne et al., 2018). Higher yields and more consistent crops can be achieved with the use of this technique. India is one country where farmers are totally dependent on the monsoon season to grow their crops. They rely heavily on weather forecasts, particularly for rain-fed agriculture. Predicting the weather and other agricultural conditions like land quality, groundwater, crop cycle and pest attack will benefit from AI technology. Farmers will be relieved of many of their anxieties thanks to AI technology's ability to accurately predict the future. When it comes to agriculture, the use of AI-powered sensors is extremely beneficial. The information will be helpful in increasing output. These sensors have a wide range of applications in agriculture. The harvesting robots can also be equipped with AI-powered sensors in order to collect data. AI-based advisories are thought to be useful in increasing production by 30%.

In farming, crop damage due to natural disasters, such as pest attacks, is the biggest obstacle to overcome. Farmers often lose their crops due to a lack of information. To safeguard their crops from cyber-attacks, farmers could benefit from this technology. This is where AI-enabled image recognition comes in. Many companies are using drones to keep an eye on production and identify any pests that might be lurking in the area. A system for monitoring and protecting crops is warranted because similar efforts have been successful in the past. Many hybrid cultivations have been developed to help farmers generate more money in a short amount of time, thanks to the advancements in technology. Use of artificial intelligence (AI) can help farmers cultivate their crops and provide a welcome environment for their customers. Using the right algorithms, it is possible to reduce food waste, which saves time and money while also promoting long-term well-being, according to data from reputable institutions. Using AI and other cutting-edge technologies, digital transformation in agriculture has a better chance of succeeding. However, all of this is contingent on the enormous amount of data that can only be gathered once or twice a year due to the production process. To keep up with the ever-changing world of agriculture, farmers have turned to artificial intelligence (AI) and the implementation of digital transformation technologies (Zimdahl, 2010).

Conclusion

Additionally, a lack of efficient irrigation systems as well as weeds and plant monitoring problems are among the issues that plague the agricultural industry. Technological advances, on the other hand, can enhance performance and so help to alleviate these problems. Artificial intelligence (AI)-driven techniques, such as remote sensors for sensing soil moisture content and GPS-assisted irrigation, can improve it. Precision weeding techniques have solved the problem of farmers losing a considerable proportion of crops during the weeding process. Pesticide and herbicide use are reduced by using autonomous robots, which are also more efficient than human labourers. Farmers may utilize drones to spray pesticides and herbicides more efficiently on their fields, and they can no longer be bothered with plant monitoring. First, a shortage of resources and jobs can be attributed to human brain power in agricultural concerns. It used to take a long time and a lot of effort to manually test agricultural attributes such as plant height, soil texture, and content. It is possible to do high-throughput phenotyping in a safe and efficient manner using a variety of different methods. This has the advantage of being flexible and advantageous, as well as providing on-demand access to data and spatial objectives.

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Smart Agriculture Technology Evaluation: A Linguistic-based MCDM Methodology

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Abstract

Agricultural operations have been highly affected by all the industrial revolutions. From ancient times to today, agrarian systems have evolved parallel to technological developments. For a decade, we have been facing a new industrial revolution, Industry 4.0. It is for sure that the existing agrarian systems will be affected by this digital transformation. Since agricultural systems are critical production networks for civilizations, their change should be addressed carefully. For that purpose, this paper focuses on the technology evaluation for Smart Agriculture (SA). The SA area is chosen thanks to its importance for sustainable development and production systems. Thus, the expectations from SA are derived from the SA advantages stated in the academic and industrial literature. Afterward, the technologies are assessed according to their ability to meet these expectations. To obtain the most powerful technology, the expectations are first weighted via the 2-Tuple Linguistic (2-TL) DEMATEL technique, then 2-TL-MARCOS is used to calculate the technology prioritization. To overcome the ambiguity about a newly emerged subject as SA, using linguistic variables via the 2-TL approach is one of the essential contributions of this paper. Moreover, this paper suggests a multi-criteria decision-making (MCDM) approach to create a comprehensive understanding of digital technologies and their use and benefits in agricultural systems. A real case study is presented with a sensitivity analysis to test the proposed methodology's applicability and replicability.

Keywords

2-Tuple Linguistic Model, DEMATEL, Digital technologies, Industry 4.0, MARCOS, Smart Agriculture

Presenter Profile

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Introduction

From ancient times until the end of the 19th century, conventional farming techniques depended on human power. Specified tools such as hoes, sickles, and pitchforks were necessary to farm (Cugno et al., 2021). Because of the massive reliability of human labor, productivity was low in such conventional techniques. By the beginning of the 20th century, developments in faster and more efficient production approach extended into the agrarian field. The 20th century was the plunge point to mechanized food production (De Clercq et al., 2018). With agricultural machinery, agrarian operations gradually transformed into a process that relied on less human power. The second revolution in the agricultural area also occurred in the 20th century with Industry 2.0 (the Second Industrial Revolution).

The third industrial revolution, Industry 3.0, introduced new software and communication technologies that upgraded the automation capacity in the production lines. After assigning oil as the primary energy source, Industry 3.0 helped to explore new and renewable energies such as hydroelectricity and wind power. By exploring new energy sources and technologies, Industry 3.0 paved the way for precision agriculture (Carrer et al., 2022).

In short, agricultural operations were highly affected by the three previous industrial revolutions. The change in the production lines was reflected in the farming activities. Currently, we are talking about the new industrial revolution called Industry 4.0. Fluctuating market conditions in a globally connected world challenge companies to continuously adapt and embrace digital transformation across all functions, including procurement, logistics, manufacturing, asset management, and factory operations (Deloitte, 2020).

Agriculture has a critical importance for civilization, with an importance that constantly increases with the depletion of natural resources. Agricultural digitalization is a agricultural industrialization's serious constituent that focuses on agricultural research, infrastructural improvements, and data services. Consequently, in this paper, the primary aim is to evaluate the digital technologies resulting in more efficient agricultural transformation. Technology transfer is crucial to transforming existing conventional systems. Therefore, this paper suggests a roadmap to follow while choosing the right and efficient technology to reach Smart Agriculture (SA).

SA is the restoration of existing farming methods with efficient, rapid, and sustainable ones (with technological integration) (Collado et al., 2019). As a topic that has emerged recently, our and experts' knowledge on this subject is fuzzy. To overcome this ambiguity, using linguistic variables in evaluations is accepted as an advantageous approach in literature (Zadeh, 1965). Hence, this paper suggests a multi-criteria decision-making (MCDM) based approach integrated with the 2-TL Linguistic (2-TL) Model (Herrera and Martínez, 2000). The MCDM approach enables a holistic analysis of the digital transformation in agriculture and its expectations based on the technologies. The use of linguistic variables is chosen to create a flexible environment for decision-making closer to the human cognitive process.

The main contributions of this paper can be summarized as follows:

- Providing a linguistic-based framework for technology assessment in an emerging field such as SA,
- Generating a deeper understanding of technology use and benefits in SA.
- Using the 2-TL-DEMATEL-MARCOS framework for the first time in the SA area.
- Investigating expectations for SA and their interrelations.

The paper's organization is as follows: Next section will provide the literature review. The following section will present the details of the suggested MCDM-based methodology. Afterward, a case study will be presented followingly its results and discussions. Finally, conclusions will be provided at the end.

Literature Review

The literature review is the critical component of the suggested methodology. Based on the academic and industrial literature, expectations from SA and related digital technologies are defined. Figure 1 indicates the mutual occurrences of digital technologies in the recent (2020-2021 and 2022) academic literature. The thickness of the lines indicates the power of mutual use, and the nodes' size indicates the number of occurrences in the recent literature. As seen from the network visualization obtained by VosViewer[8], the digital technologies are highly stated in the SA area. The network visualization also defined two different clusters for the technologies.

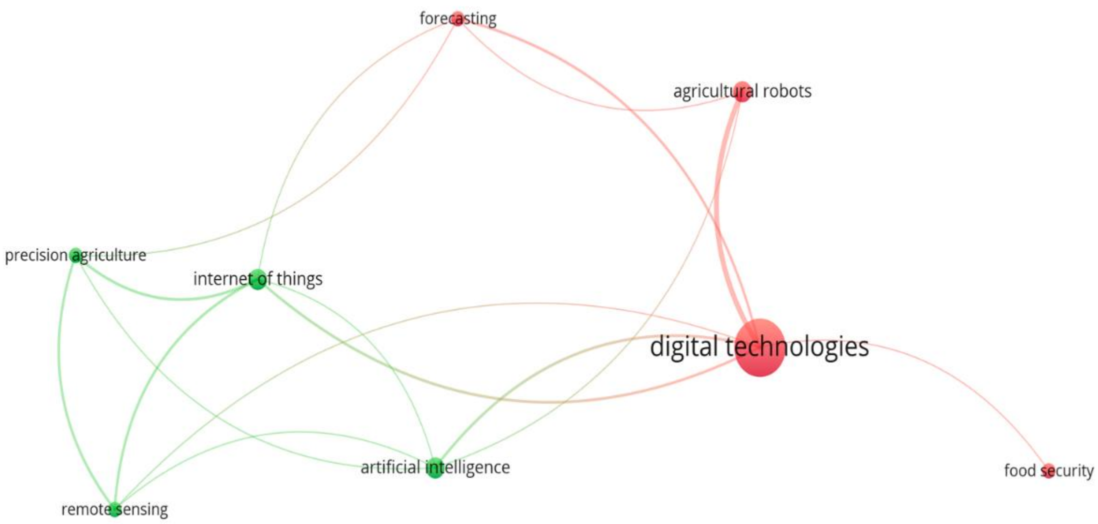


Figure 1: Network visualization of keyword occurrences of digital technologies in SA.

The green group is concentrated chiefly on precision agriculture, which emphasizes the use of information technologies (IT) for more efficient crop production (Agrawal et al., 2020; Carrer et al., 2022; Dhillon et al., 2020; Ivanovski et al., 2020; Maffezzoli et al., 2021). IoT, remote sensing technologies, and their integration with artificial intelligence (AI) are critical for that purpose. Under the AI technologies, we can also count Machine Learning (ML) and Deep Learning (DL) (Costa et al., 2021). Their integration is crucial for reaching "precision" or "smart" agriculture.

The other group, the red one, primarily emphasizes automation in agriculture using robotic technologies (Cubero et al., 2020; Dharmasena et al., 2019; Gorlov et al., 2020; Singh and Kaur, 2021). At this part, with automation, the control over agricultural production is increased. Consequently, food security can be handled by integrating Blockchain technology and forecasting technologies based on AI/DL/ML and Big Data. As the "digital technologies" node is the biggest one, it can be concluded that their use in SA is critically vital for agricultural

[8] https://www.vosviewer.com

transformation. Based on their critical importance in agricultural transformation, this paper focuses on assessing and choosing the most appropriate technology to ensure the expectations from SA.

The expectations from the SA are also generated from the academic and industrial literature. The expectations' foundations are based on the advantages stated in the SA literature. They will be used as evaluation criteria to define the technologies' ability to meet expectations for the technology evaluation process. The following table gives the detected five main expectations from SA.

Table 1: Expectations from SA (Abioye et al., 2020; Ait Issad et al., 2019; "Building partnerships for sustainable agriculture and food security," n.d.; Collado et al., 2019; Deloitte, 2020; McKinsey and Co., 2020)

E#	Expectations from SA
E1	Efficient strategy generation
E2	Risk Management
E3	Trustable, on-time data
E4	Resource optimization
E5	Food security

The following section will provide more information about the suggested model for tech ology evaluation and the details of the proposer integrated MCDM techniques.

Methods

This section gives the preliminaries of the recommended methodology. The first section provides basic concepts of the 2-TL model and its benefits. Then the standard DEMATEL method is explained briefly with the group decision-making (GDM) technique. The technique used for technology evaluation, 2-TL MARCOS, is presented in detail at the end.

Figure 2 summarizes the general concept of the suggested model. Here expectations are the evaluation criteria and the technologies approach as alternatives in the 2-TL-MARCOS methodology. As seen from the figure, an assessment matrix is formed to assess the technologies based on their ability to meet the criteria.

During the evaluations, linguistic variables are essential to creating an unbiased, flexible environment for decision-makers (DMs). Using the 2-TL model enables computation and analysis closer to human cognitive processes. The model contains two stages:

1) The weighting of criteria (expectations) via 2-TL DEMATEL
2) Prioritization of technologies via 2-TL MARCOS.

In both stages, the GDM approach is integrated with 2-TL DEMATEL and MARCOS to create an unbiased decision-making environment. Plus, the Delphi approach is followed during collecting assessments from DMs.

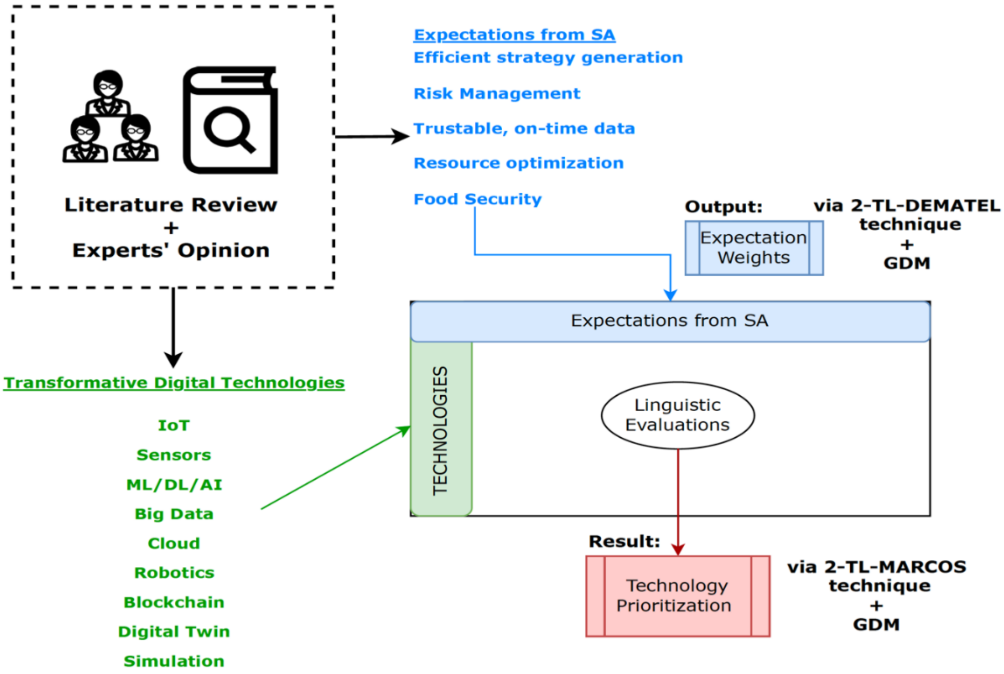


Figure 2: Suggested model for technology assessment for SA.

2-TL Linguistic Model

The 2-TL linguistic approach is first unveiled by (Herrera and Martínez, 2000). This model helps to work with heterogeneous information. Besides, it can handle multi-granular information. It is suitable for GDM, where group members have different experiences about the same subject. The 2-TL linguistic model is generally used with various MCDM models to emphasize their ability to deal with linguistic data and diminish data loss during the translation phase (Buyukozkan and Uzturk, 2017; Geng et al., 2017; Karsak and Dursun, 2015).

The 2-TL fuzzy linguistic representation model represents the linguistic information using a 2-TL (*S, α)* here; *S* is a linguistic label, and *α* is a numerical value representing the value of the symbolic translation. The function is defined as:

$$\Delta_s : [0, g] \rightarrow \bar{S}$$

$$\Delta_s(\beta) = (S_i, \alpha), with \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases}$$

The linguistic term set *S* could be converted into 2-TL form by adding zero value as in the

$$S_i \in S \Rightarrow (S_i, 0)$$

following relation:

The 2-TL linguistic model, a linguistic, symbolic computational model, modifies the fuzzy linguistic approach by including a parameter to the linguistic representation to increase the accuracy and the interpretability of the results (Martínez et al., 2015). The 2-TL linguistic model enables us to deal with variables closer to the human beings' cognitive processes and augment the computations' accuracy. For further details about the 2-TL model, readers can refer to (Martínez et al., 2015).

DEMATEL

DEMATEL (Gabus and Fontela, 1972) is an accurate MCDM tool that depicts the importance of related criteria. It also makes it possible to determine the causal relationships between evaluation criteria (Büyüközkan and Öztürkcan, 2010; Quader et al., 2016) and is suggested for the criteria weighting process. It is utilized in this study's framework because of its ability to check the interdependence among the proposed criteria and extract their interrelationships. Evaluating these relationships can help practitioners or policymakers to increase the evaluation processes' efficiency.

Group Decision Making

MCDM aims to discover the most appropriate alternative by conceiving multiple criteria concurrently. GDM may be adequate to reach an objective solution in this procedure. GDM involves various DMs having different backgrounds or points of view and handling the decision process distinctive from others. However, each DM has shared awareness of cooperating with each other to achieve a collective decision. While having haziness and uncertainty, reaching a consensus for a decision in a group with different opinions turns out to be more critical. Generally, GDM problems are solved using classic approaches, such as the majority rule, minority rule, or total agreement. Yet, these techniques do not assure an acceptable solution for all DMs (Büyüközkan and Güleryüz, 2015).

In this paper, a consensus-reaching process is followed by the Delphi approach. Delphi is a communication instrument that facilitates group decision-making. The Delphi process is very efficient for supporting a group of individuals to handle complicated problems as a group. The method is based on expert knowledge, and the group is principally formed with knowledgeable and expert contributors (Büyüközkan et al., 2004).

The assessment made by DMs depends on their judgment and is subjective. Accordingly, instead of crisp numbers, the linguistic variables are given to the DMs to represent their data's uncertain and subjective nature.

MARCOS Method

The MARCOS method is based on defining the relationship between alternatives and reference values (ideal and anti-ideal alternatives). Based on the determined relationships, the utility functions of options are determined, and compromise ranking is made concerning ideal and anti-ideal solutions. Utility functions represent the position of an alternative concerning an ideal and anti-ideal solution. Decision preferences are defined based on utility functions. The best option is the one closest to the ideal and, at the same time, furthest from the anti-ideal reference point.

The advantages of the MARCOS method are (Stević et al., 2020):

- the consideration of an anti-ideal and ideal solution at the very beginning of the formation of an initial matrix,
- closer determination of utility degree concerning both solutions,
- the proposal of a new way to determine utility functions and their aggregation,

- the possibility to consider a large set of criteria and alternatives while maintaining the method's stability.

MARCOS method is used for various MCDM problems in literature. Even if it is a newly introduced technique, it has been used for multiple sectors and areas (Du et al., 2022; Gamal et al., 2022; Khosravi et al., 2022; Rakhmangulov et al., 2022).

The MARCOS method is like the TOPSIS method; it covers seven uncomplicated steps to reach an optimum solution closer to the compromise solution (Stević et al., 2020). Also, the extension of the MARCOS method with the 2-TL linguistic model augments its flexibility and the interpretability of the results for complicated and ambiguous application areas.

To the best of our knowledge, the MARCOS method has not been used in SA. Besides, the 2-TL extension of MARCOS have not been applied in MCDM literature. Accordingly, to emphasize the MARCOS method's accuracy with linguistic variables and augment the objectiveness in decision-making, this paper provides a 2-TL MARCOS framework for smart agriculture technology evaluation.

2-TL MARCOS Method

The 2-TL MARCOS method is performed through the following steps:

Step 1: Forming the initial decision-making matrix.

Matrix D is the aggregated assessments of *l* DMs where $d_{ij} = \{d_{ij}^1, d_{ij}^2, d_{ij}^3 \dots, d_{ij}^l\}$ contains the relative importance of criterion *i* in relation to alternative *j* and $d_{ij} = (s_1, \alpha_1)$ includes the 2-TL linguistic values assigned by DMs.

$$D = [d_{ij}] = \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \tag{1}$$

By applying 2-TL aggregation operators such as 2-TL arithmetic mean, 2-TL weighted average, L2TOWA operator etc. In this 2-TL MARCOS model, we suggest using the 2-TL weighted average operator as in Eq. (2):

$$\bar{x}^w\big((s_1, \alpha_1), (s_2, \alpha_2), \dots, (s_l, \alpha_l)\big) = \Delta\left(\frac{\sum_{i=1}^l \Delta^{-1}(s_i, \alpha_i). w_i}{\sum_{i=1}^l w_i}\right) = \Delta\left(\frac{\sum_{i=1}^l \beta_i. w_i}{\sum_{i=1}^l w_i}\right) \tag{2}$$

where, *l* is the number of DMs, $\{(s_1, \alpha_1), (s_2, \alpha_2), \dots, (s_l, \alpha_l)\}$ is a set of 2-TL linguistic values and $W = \{w_1, w_2, \dots, w_l\}$ is their associated wights.

Step 2: Forming the extended initial matrix.

This step is to define the ideal *(AI)* and anti-ideal *(AAI)* solutions. Depending on the nature of the criteria, *AI* and *AAI* values are obtained with the following equations

$$\begin{aligned} AAI &= \min_i d_{ij} \ if \ j \in beneficial \ criteria \ and \ \max_i d_{ij} \ if \ j \epsilon \ cost \ criteria \\ AI &= \max_i d_{ij} \ if \ j \in beneficial \ criteria \ and \ \min_i d_{ij} \ if \ j \epsilon \ cost \ criteria \end{aligned} \tag{3}$$

Step 3: Normalizing the extended initial matrix to obtain the normalized matrix *(N).* The following equations give the elements of the matrix *N*.

$$n_{ij} = (n_{ij}, \alpha_{ij}) = \Delta\left(\frac{\Delta^{-1}(d_{ai})}{\Delta^{-1}(d_{ij})}\right) \; if\ j\ is\ cost\ criteria$$
$$n_{ij} = (n_{ij}, \alpha_{ij}) = \Delta\left(\frac{\Delta^{-1}(d_{ij})}{\Delta^{-1}(d_{ai})}\right) \; if\ j\ is\ benefit\ criteria \tag{4}$$

Step 4: Obtaining the weighted matrix.

The weighted matrix *V* is obtained by multiplying the normalized matrix *N* with the weight coefficients.

$$(v_{ij}, \alpha_{ij}) = \Delta(\Delta^{-1}(n_{ij}, \alpha_{ij}) \otimes \Delta^{-1}(w_{ij}, \alpha_{ij})) \tag{5}$$

Step 5: Calculating the utility degree of alternatives *(K_i).*

$$(K_i^-, \alpha_i) = \Delta\left(\frac{\Delta^{-1}(s_i, \alpha_i)}{\Delta^{-1}(s_{aai}, \alpha_{aai})}\right)$$
$$(K_i^+, \alpha_i) = \Delta\left(\frac{\Delta^{-1}(s_i, \alpha_i)}{\Delta^{-1}(s_{ai}, \alpha_{ai})}\right) \tag{6}$$

where (s_i, α_i) presents the sum of the elements in the weighted matrix *V.* It can be obtained by the following equation:

$$(s_i, \alpha_i) = \sum_{i=1}^{n} (v_{ij}, \alpha_{ij}) \tag{7}$$

Step 6: Obtaining the utility function *($f(K_i)$)* of alternatives with the following equation:

$$(f(Ki), \alpha_i) = \Delta\left(\frac{\Delta^{-1}(K_i^+, \alpha_i) + \Delta^{-1}(K_i^-, \alpha_i)}{1 + \frac{1 - \Delta^{-1}(f(Ki^+), \alpha_i))}{\Delta^{-1}(f(Ki^+), \alpha_i)} + \frac{1 - \Delta^{-1}(f(Ki^-), \alpha_i))}{\Delta^{-1}(f(Ki^-), \alpha_i)}}\right) \tag{8}$$

where $(f(Ki^-), \alpha_i)$ is the utility function in relation to the anti-ideal solution and $(f(Ki^+), \alpha_i)$ represents the utility function in relation to the ideal solution. They can be obtained by the following equations:

$$(f(Ki^-), \alpha_i) = \Delta\left(\frac{\Delta^{-1}(K_i^+, \alpha_i)}{\Delta^{-1}((K_i^+, \alpha_i) + \Delta^{-1}((K_i^-, \alpha_i)}\right)$$
$$(f(Ki^+), \alpha_i) = \Delta\left(\frac{\Delta^{-1}(K_i^-, \alpha_i)}{\Delta^{-1}((K_i^+, \alpha_i) + \Delta^{-1}((K_i^-, \alpha_i)}\right) \tag{9}$$

Step 7: Alternative prioritization.

The alternatives' prioritization is based on the final values of utility functions. The most appropriate option is the one with the highest score.

Case Study

In this section, a case study is suggested to test the plausibility of our suggested framework. The model has two stages; a decision-making group is formed from three different experts for both stages. What we expect from the experts is first to determine the relations between expectations for 2-TL-DEMATEL and then determine the ability of technologies to meet the expectations for 2-TL-MARCOS.

Different sets are offered mainly to make DMs comfortable during their assessments and provide them a flexible environment to express their opinions about the subjects. The three experts have diverse backgrounds in digital technologies and SA. Accordingly, two different linguistic sets are provided to them for their assessments. Here Table 2 gives the details of linguistic sets.

Table 2: Linguistic sets provided to DMs.

2-TL sets	
S^5	*None (N)-Low(L)- Medium (M)- High(H)-Perfect(P)*
S^9	*None (N)-Low (L)-Medium Low (ML)-Almost Medium (AM)- Medium (M)-Almost High (AH)-High(H)- Very High (VH)-Perfect(P)*

Stage 1: Calculating the expectation weights and their interrelations.

The assessments for pairwise comparisons are obtained from the decision-making group. We have worked with three experts; two of them are highly experienced in digital technologies and the SA area. The third expert is only experienced in digital technologies and is less experienced in SA. Accordingly, we have provided S^9 for two experts more experienced in SA*;* S^5 *for* the third. Table 3 provides the linguistic assessments of DM1 as an example, and followingly, Table 4 presents the aggregated initial decision matrix.

After applying 2-TL-DEMATEL steps, the weights of the expectations are obtained followingly: *Efficient strategy generation, (M, 0.29*); *Risk management, (M,0.11)*; *Trustable, on-time data, (M, -0.15)*; *Resource optimization, (AM, 0.02*); *Food security, (M, -0.11)*. Further analysis will be given in the Results and Discussions section.

Table 3: Assessments for DM1.

Smart Agriculture Expectations	Efficient strategy generation	Risk Management	Trustable on-time data	Resource optimization	Food Security
Efficient strategy generation	0.00	P	L	AH	H
Risk management	VH	0.00	L	M	VH
Trustable, on-time data	H	H	0.00	VH	AH
Resource optimization	ML	ML	L	0.00	AM
Food Security	M	ML	ML	L	0.00

Table 4: Aggregated initial decision matrix.

Smart Agriculture Expectations	Efficient strategy generation	Risk Management	Trustable on-time data	Resource optimization	Food Security
Efficient strategy generation	0.00	(AM, -0.20)	(L, -0.45)	(ML, -0.05)	(ML, -0.38)
Risk management	(AM, -0.47)	0.00	(L, 0.43)	(L, 0.40)	(AM, -0.35)
Trustable, on-time data	(ML, 0.10)	(ML, 0.10)	0.00	(ML, -0.48)	(ML, -0.12)
Resource optimization	(L, -0.25)	(L, -0.02)	(L, -0.45)	0.00	(L, 0.13)
Food Security	(L,0.28)	(L, -0.18)	(L, -0.42)	(VL,0.43)	0.00

Stage 2: Technology prioritization according to the expectations.

This stage is to assess the technologies according to their ability to meet the expectations of SA. Based on this target, each DM evaluated technologies according to the expectations in the previous stage. Plus, the expectation weights will be used as criteria wight at this stage. The aggregated evaluation matrix is given in Table 5.

After obtaining Table 5, the 2-TL-MARCOS steps provided in the previous section are applied. According to the results, a ranking of technologies according to their ability to meet the expectations is obtained. The detail of the results and a sensitivity analysis will be given in the next section.

Table 5: Aggregated evaluation matrix for 2-TL-MARCOS.

	Efficient strategy generation	**Risk Management**	**Trustable on-time data**	**Resource optimization**	**Food Security**
IoT	(L, 0.2)	(ML, -0.17)	(AM, -0.35)	(AM,0.20)	(ML, -0.17)
Sensors	(L,0.25)	(ML, 0.10)	(ML,0.37)	(ML,0.37)	(L,0.40)
ML/DL/AI	(AM, -0.35)	(ML, 0.48)	(L, -0.15)	(ML, -0.05)	(ML, 0.10)
Big Data	(ML, -0.05)	(ML, -0.05)	(AM,0.20)	(ML,0.48)	(ML, -0.05)
Cloud	(ML, -0.37)	(L,0.40)	(ML, 0.10)	(L,0.13)	(L, -0.42)
Robotics	(L, -0.42)	(ML, -0.05)	(L, -0.45)	(AM, -0.47)	(L,0.40)
Blockchain	(L,0.33)	(ML, -0.17)	(ML, 0.10)	(ML, 0.10)	(AM,0.20)
Digital Twin	(AM,0.20)	(AM,0.20)	(L, -0.45)	(AM, -0.35)	(AM, -0.35)
Simulation	(ML, -0.38)	(AM, -0.35)	(L, -0.30)	(ML, 0.10)	(ML, -0.05)
AI	**(AM,0.20)**	**(AM,0.20)**	**(AM,0.20)**	**(AM,0.20)**	**(AM,0.20)**
AAI	**(L, -0.42)**	**(L,0.40)**	**(L, -0.45)**	**(L,0.13)**	**(L, -0.42)**

Results and Discussions

The 2-TL-DEMATEL-MARCOS methodology is applied for the technology prioritization for SA. In the first stage, the expectation weights are obtained via the 2-TL-DEMATEL technique. The weights are presented in the linguistic form in the previous section, but their percentage weights are given in Figure 3 to better show their distribution for SA. As it can be seen from the figure, their importance is close. According to the numbers, it is easy to assume that

“Efficient strategy generation” seems to be the most critical expectation for SA. However, when the (D-R) values for each expectation are examined, cause-effect relations are obtained for expectations. If *(D-R)>0,* it means that the degree of affecting others is more substantial than the degree of being affected. Therefore, “Efficient strategy generation” is affected by two expectations: “Resource optimization” and “Food Security.” “Food security” is the third important expectation; yet concentrating on this expectation may provide a deeper impact on the transformation of agricultural systems. The (D+R) and (D-R) values are given in Figure 4. Accordingly, expectations 1,2,3 are influenced by other criteria.

(D+R) values stated in Figure 4 also state their importance. Accordingly, parallel to 2-TL-DEMATEL results, (D+R) values also show a similar ranking for expectation importance.

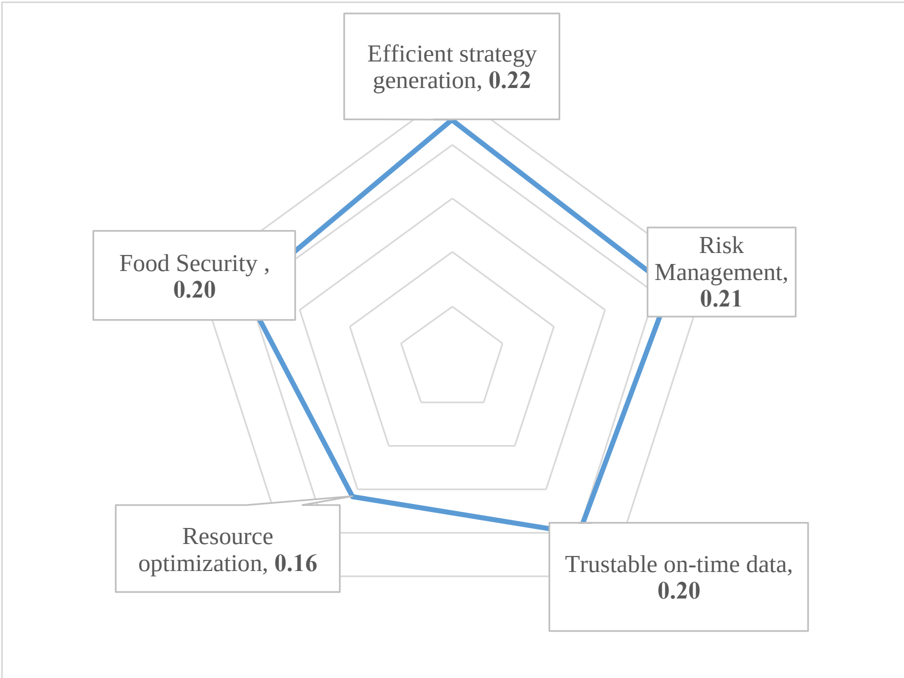


Figure 3: Expectation weighs on the radar chart.

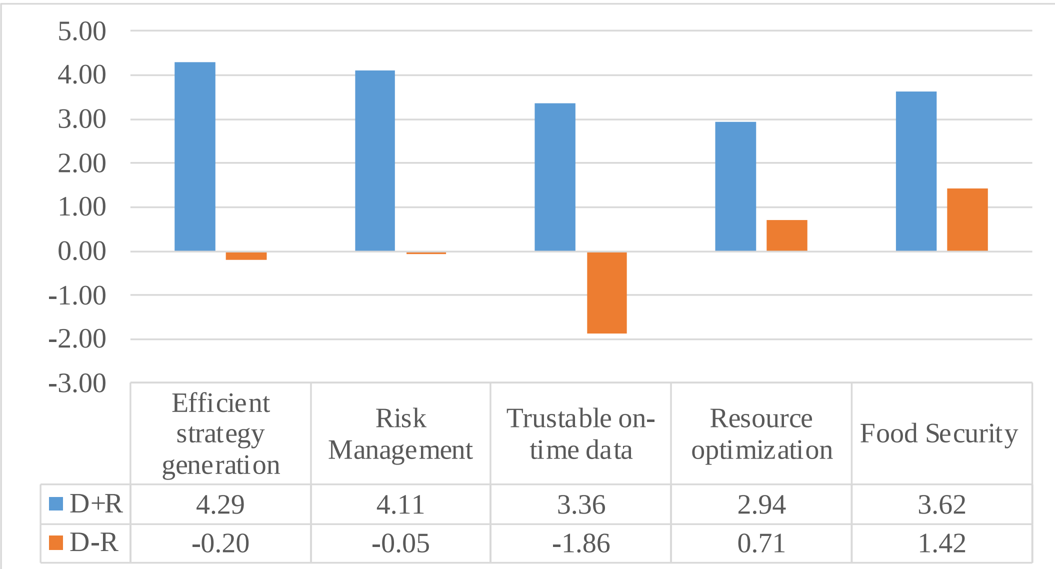
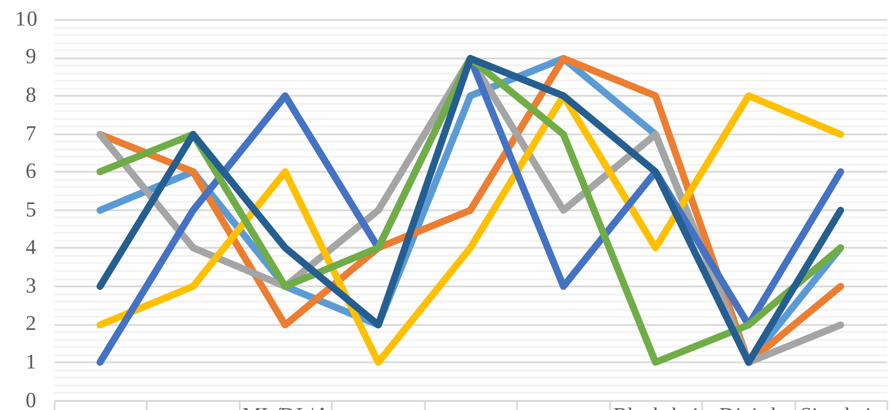


Figure 4: (D+R) and (D-R) values for expectations

Moreover, a sensitivity analysis to test the applicability under changing conditions. As stated in Figure 5, six different scenarios are generated, each emphasizing one expectation and last with equal weights. According to our case study, the most effective and moving technology for SA is selected as *Digital Twin*. When the different cases are compared, *Digital Twin* is still the one technology that is mostly ranked the first under different circumstances.

A *Digital Twin* is a digital equal of an actual entity that reflects its performances and states over its lifetime in a virtual space (Verdouw et al., 2021). Using Digital Twins as a management tool for farms allows aggregation of physical flows from its planning and control. Since the *Digital Twin* technology contains programming and AI/ML/DL together, maybe we can assume that the integration of ML/DL/AI together with programming may be the most powerful transforming milestone for conventional farming.



	IoT	Sensors	ML/DL/AI	Big Data	Cloud	Robotics	Blockchain	Digital Twin	Simulation
Case Study	5	6	3	2	8	9	7	1	4
Case 1	7	6	2	4	5	9	8	1	3
Case 2	7	4	3	5	9	5	7	1	2
Case 3	2	3	6	1	4	8	4	8	7
Case 4	1	5	8	4	9	3	6	2	6
Case 5	6	7	3	4	9	7	1	2	4
Case 6	3	7	4	2	9	8	6	1	5

Figure 5: Sensitivity analysis and case study results.

Conclusions

This paper suggests a linguistic-based MCDM methodology for the technology evaluations in SA. The SA area is chosen thanks to its importance for sustainable development. Also, with Industry 4.0, we face new production systems approaches. Since agriculture is civilization's most critical production network, its digital transformation should be addressed carefully. Therefore, the expectations from SA are derived from the SA advantages stated in the academic and industrial literature. Afterward, the technologies are assessed according to their ability to meet these expectations. To obtain the most powerful technology, first, the expectations are weighted via the 2-TL-DEMATEL technique, and then 2-TL-MARCOS is used to calculate the ranking.

According to the case study, the most prominent technology to meet the expectations is chosen as a *Digital Twin*. Yet, by analyzing these results, underlining the importance of AI/DL/ML technologies is necessary. For future studies, more analysis may be applied for further analysis of technologies and their dependencies. The 2-TL-MARCOS technique can be compared to other 2-TL-based methodologies. Moreover, by updating the expectation criteria, the same methodology can be applied to other sectors such as supply chain and construction.

In this study, the main limitation is the number of DMs used in the case. The number of DMs can be augmented to reach a more objective solution. Also, for future studies, a large group decision-making model can be applied to the same problem to cover more end-users and obtain real stakeholder opinion for expectation weighting.

Acknowledgments

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A Technology Mapping Approach to the Value Proposition for Agri-food Firms and Supply Chains of Digital Transformation

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Abstract

Despite the promise of substantial gains from digital transformation, its incidence remains low in the agri-food sector and the broader food system. Understanding of the transformation process is somewhat well developed, but not as it occurs on farms and in agri-food supply chains. Contemporary pressures on the agri-food sectors advocated for improvements in multiple facets of performance. Digital technologies are increasingly looked to as a means of performance improvement. Practical interpretation of the value proposition offered by digital technology to the agri-food sector has not been implemented as a generalisable decision tool. Sustainability, resilience, and natural cycles for material and energy are of increasing performance relevance but have not been analytically linked to agri-food's digital transformation. Quantification of benefits and costs has not been widely attempted. The current paper presents an empirical study employing technology mapping to quantify costs and benefits of technological change in the agri-food system. It identifies Research and Development impetus for change by mapping research output to high value technologies for a selection of industries. Particular emphasis is given to production tasks amenable to digital adoption, and to the transformations generating subsequent value within and beyond the adopter's enterprise. Decision tools are developed to guide investment by private, public and industry stakeholders, in response to forms and magnitudes of benefit and cost. This paper outlines the methodology used, preliminary results, and prototype decision tools. Conflicts arising between performance metrics are identified and solutions proposed. The implications for stakeholders of a more visible and quantifiable value proposition for digital transformation are discussed in the contexts of received opinion about the effects of digital agriculture and the current and strategic needs of firms, industry and society.

Keywords

Digital Transformation; Agri-food; Value Proposition; Technology Mapping.

Presenter Profile

Derek Baker is a research manager with 30 years' experience in agribusiness and development. He is currently a Visiting Research Fellow at Australia's Food Agility Co-operative Research Corporation, and Professor of Agribusiness and Value Chains at the University of New England in Australia. He is Director of UNE's Centre for Agribusiness. He was formerly Program Manager for Value Chains and Trade at the CGIAR's International Livestock Research Institute, and Program Manager in Food Chain Innovation at The Food, Resource and Agricultural Research Institute in Denmark. Derek has worked in over 30 countries.

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Introduction

Agri-food digital transformation is attractive, but implementation is slow, lagging behind that in other industries (Blackburn et al., 2020; Trendov et al., 2019). Slow adoption offers a partial explanation (Cook et al., 2021; Leonard et al., 2019). Transformation associated with new business models, particularly where data flows are transformed to generate benefits (Wolfert et al., 2017), is less commonly observed and quantified in the food system (Wysel et al., 2021).

Many barriers to adoption, and to digital transformation, are well recognised. These include knowledge and availability of technology, and practical aspects of its implementation (Darnell et al., 2018; Rijswijk et al., 2021; Young, 2018). Value proposition is also missing: partly due to knowledge gaps about what known digital technology has to offer the context of specific tasks; and partly regarding unknown or emerging technology. Further, incompatibilities in incentives along the supply chain are known to generate chain failure, as a special case of market failure associated with excludable but non-rival services within the supply chain (Cook et al., 2021).

The use of first principles – decomposition of tasks into costly components - in identifying costs and benefits of change has been demonstrated widely (Barnes et al., 2019; Meyer-Aurich et al., 2008). Associated indicators for digital technologies have been listed by various authors by management variable (Jakku et a;., 2022) or by technology choice (Saiz-Rubio et al., 2020), or management procedure (Fleming et al., 2021). Aspects of the evaluation of information-based change have been outlined by various authors. Synergies, scale and scope effects are discernible due to patterns of marginal cost and benefit as systems are expanded or combined (Sykuta, 2017), although capacities for this accumulation of benefit are unknown and add uncertainty to decisions. Overall, there is a paucity of research evidence for the benefits of digital adoption and transformation, particularly with regard to the lack of a specified counterfactual for analysis (Klerkx et al., 2019; Banhazi et al., 2011).

Bibliographic searches have widely used in matching emerging technologies to existing applications (Pallottino et al., 2018), and particularly in characterising potential applications (Park et al., 2015). Based on mechanical keyword searches, specific tasks within or between supply chain stages are matched to published research and commercialisation outcomes.

A multitude of investment decision tools surrounding risks and returns are available. Their principles are employed to extend these tools to investment in technology adoption and onwards to transformation. They are broadened to characterise chain failure and evaluate alternative corrective strategies at industry and societal level in pursuit of a range of performance objectives. Similarly, technology choices are addressed in light of mapped research outcomes.

Methods

Projected value is measured as Present Discounted Value associated with several stages of digital transformation. This extends from adoption of a technology for a task, through its combined and cumulative effect on the existing system due to synergies in costs and benefits, to holistic change in the business model due to new sources of value associated with the technology.

Technology mapping has two phases. First, producer and supply chain actors are interviewed to identify costly production and marketing tasks. These are decomposed using existing literature on production methods, and mapped to potential digital solutions for which financial implications are assessed. These estimates are progressed from adoption though to transformation. This phase enables quantification of a value proposition. The second phase entails beneficial changes being mapped to ongoing research by bibliographic search methods. This identifies desirable R&D pathways and roles, and adds a dynamic, longer term, and societal component to the value proposition.

Decision tools employ the PDV measures and factor found to affect the magnitude and incidence of net benefits with and between stage in the supply chain, and in terms of non-price-related benefits such as sustainability. The tools are then used to evaluate investment by private and industry actors, as well as by government in cases of chain failure. These form the basis for sectoral-level strategies.

Results

Results of the study are not yet available. This paper will detail preliminary results and present their practical implications.

Results will feature task decomposition from 2-3 production and supply chain systems, and the costs and benefits with and without selected digital and non-digital interventions. These will be valued individually and collectively.

Discussion

Discussion will centre on the raw results and their progressive changes as tasks and digital investments are combined in various ways, and their orientation around digital assets accumulated along the supply chain.

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Keynote Presentation: Food chain strategies to achieve zero GHG by 2050

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Presenters profile

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Investigating EKC in oil-exporting countries

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Extended Abstract

The main goal of COP26 international climate conference 2021 was to reach an agreement to safeguard a global net-zero by mid-century and was described as the world's "last best chance to get runaway climate change under control". Nevertheless, many questions remain unsolved and especially about how realistic will be the outcomes. Furthermore, some sources suggest that some of the world's major fossil fuel and meat-producing countries are lobbying against comprehensive climate change action. Thus, studies and policy recommendations about the impacts of environmental degradation and disentangling its main factors remain extremely important. Oil exporting countries are accused to be the highest polluters, especially those exhibiting very low economic diversification and weak institutional framework. This work aims at contributing to the existing literature by investigating EKC hypothesis in a large set of oil-exporting countries during a long period and taking into account an extended set of potential variables and technics.

Literature review

The relationship between economic growth and the environment is complex and the related literature provides mixed results. In the current era of technology, sustainable economic growth depends to a great extent on energy consumption. There are plenty empirical studies that examined the EKC hypothesis, however, the empirical results are inconclusive. Focusing on oil producing countries, Saboori et al., (2016) explore the environmental Kuznets curve (EKC) hypothesis in OPEC's members, during the period 1977–2008. The empirical results confirm the existence of EKC in six countries of 10 countries under review. Further, causality tests reveal that oil consumption, labour, and capital are the most influential factors in the fluctuation of ecological footprint. Recently, Ike et al., (2020) implement the novel Method of Moments Quantile Regression (MMQR) with fixed effects to investigate the dynamic relationship between oil production and CO2 emissions in 15 oil-producing countries from 1980 to 2010 considering electricity production, democracy, and trade. Authors find an inverted U-shape relationship between economic growth and carbon emissions only in the median and higher emission countries. More interesting, they find that electricity production intensifies CO2 emissions. Onifade (2022) studies the validity of the Environmental Kuznets Curve (EKC) hypothesis in a sectoral composition framework in four African oil-rich countries, including Algeria, Nigeria, Angola, and Egypt for the period 1995 to 2016. The empirical analysis suggests that fossil energy consumption, income levels, and the shares of the manufacturing sector significantly increase environmental pollution. However, the EKC hypothesis is not confirmed for the countries under study. Furthermore, its validity reveals significant quantile effects. In the same way, Ouédraogo et al., (2021) test the EKC hypothesis in eleven African oil-producing countries from 1980 to 2014. The authors conclude that EKC is confirmed in Cameroun only, while the other countries exhibit U-shaped in the remaining countries. Al-Khars et al. (2022) provide a good literature review for studies treating EKC hypothesis in Gulf Cooperation Council countries, which represent major global oil producers. We have noticed that the studies reviewed reveal many weaknesses including a small number of oil-producing countries in the sample, a short period of study, and a limited number of empirical models. Thus, the principal objective of our study is to evaluate the potential effect of economic development, energy consumption, globalization trade, and political regime on environmental quality in oil-exporting economies around the world over the period 1984 to 2019 in 24 oil-exporting countries using an extended set of models.

Data and Methods

Trying to investigate a modified EKC hypothesis, we have collected annual data from several databases for twenty-four (24) oil-exporting economies over the period 1984-2019. The empirical analysis is based on panel data estimations. We begin with the descriptive analysis before running any econometric equation. Thereafter, cross-sectional dependency and panel unit root tests have to be taken into account. Thereupon, long-run equilibrium cointegration relationship is tested. Finally, feasible gls models controlling for group wise heteroskedasticity and autocorrelation, driscoll-kraay standard errors specifications addressing for cross-sectional dependency and quantile regression approaches with nonadditive fixed effects when non-lineal and varying effects at different points of the outcome variable distribution are also utilized. For robustness, dynamic GMM-system specifications are also utilized.

Empirical results

Empirical results support there is a positive but non-linear association between environmental degradation and economic development. That means that EKC seems to be validated for oil-exporting economies. However, the impact of economic development is asymmetric with respect to the level of environmental degradation leading to possible differential policy-making proposals. Also, the use of energy is the most important negative parameter of pollution among oil-exporting countries. Additionally, findings support the negative key role of trade openness on environmental abasement. Furthermore, we found that government institutional quality does matter for the environment. In particular, it was found that as the democracy index increases environmental quality is also better. In other words, more democratic economies care more about the quality of the environment and so take measures for CO2 emissions reduction.

Concluding remarks

The current study suggests directions for policymakers in oil-exporting countries to ensure environmental sustainability. The demand mitigation of energy should be reliant on renewable sources. Moreover, governments in oil-exporting countries should enhance environment-friendly investments. Importantly, they have to embark on environmental awareness campaigns to diffuse knowledge about environmental risks and how to mitigate them.

Keywords

Environmental sustainability; Economic development; Oil exporters; EKC; Panel data analysis

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Environmental sustainability, energy consumption and economic growth: empirical evidence from OECD countries

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Extended Abstract

Rapid economic growth has clearly been evident for many countries all over the world for the last 3-4 decades, but it came with a cost on the environment, putting enormous pressure on the ecological carrying capacity of the planet. In order to expand, the economies use up the limited resources and emits waste that pollutes the natural environment. Hence, in the long term, environmental degradation challenges the very foundation upon which economic growth is built.

Future generations will have inadequate natural resources, and the crucial task for all countries and government authorities is thus to achieve environmentally sustainable economic growth. There are many studies investigated the relationship between growth and environment in developed countries, mainly because of the availability of environmental data. We will try to collect data for both advanced and developing countries and analyse the whole sample but also the subsamples of countries based on income level.

The principal objective of our study is to evaluate the extent to which economic development, energy … affect environmental sustainability in OECD countries over the period 2014-2019. We will mainly focus on the relationship of sustainability index with economic growth, different types of energy consumption, CO2 emissions, human capital, trade openness, population density and life expectancy. So, we will also use those indicators to assess the environmental sustainability of in developed and emerging economies across our sample.

Methods

Due to data availability of a short period of six (6) years panel data, empirical analysis is based on generalized methods of moments (GMM) techniques. In particular, one step and two steps GMM approaches are employed.

Results & Discussion

Empirical results support there is a positive association between environmental sustainability and economic growth; the more developed is a country the higher the environmental sustainability as expected. The use of renewable and nuclear energy enhances the environment while, petroleum, coal and natural gas downgrade environmental quality. Additionally, findings support the positive key role of human and physical capital, trade openness and life expectancy across OECD countries. On the contrary, population density seems to negatively affect environmental sustainability.

(Example) A panel data set of the 28 EU countries, over the period 2000-2018 (material recycling) and 2010-2017 (materials circularity) was employed. The average rate of circularity

within Europe is 8.6% but excluding Netherlands, which is an outlier, the average circularity rate drops to 7.9%.

We tried to identify the main socio-economic determinants of inter-country differences in materials recycling and circularity rates. In particular, the empirical findings indicate that GDP per capita has a positive impact on both materials recycling and circularity rates within Europe indicating that richer economies, as expected, seem to take more actions towards recycling and circularity. Fertility rate has a positive impact on recycling and circularity rate. Higher fertility rate indicates more people in the young cohort who might be more likely to carry our pro-environmental behaviour. The impact of education is also positive to recycling indicating that countries with higher educated people ratios tend to recycle more. On the contrary, the level of research and development expenditures is focused on industry and so they matter for materials circulating. R&D programs are essential for the advanced necessary technology of waste and wastewater management, since without scientific research and development several environmental issues may arise. Environmental taxes, even if become a much-debated issue in environmental policy, seem to significantly matter in the level of materials recycling and circularity. Finally, urbanization process is used as a proxy of the level of materials' recycling and circulating.

Keywords

Circular economy; recycling; time series analysis.

Sustainable food value chains in the European Union: Linking policies and multi-stakeholders' initiatives

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Abstract

This paper undertakes a systematic review of EU policies, regulations, food standards, financial mechanisms, and industrial and consumers initiatives aiming to achieve a sustainable food value chain (FVC) in Europe. We map priorities of different initiatives and link them to the food-related Sustainable Development Goals (SDGs) and their corresponding targets. This enables spotting potential interactions and political gaps in the EU green agenda, while strengthening integrated action to build a resilient and sustainable FVC. The results reveal the existence of overall synergies with the food-related SDGs, but also political gaps concerning solid a sustainable framework as proposed by SDG 12.1, chemical management, and sustainable public procurement at the national level. Furthermore, political action comprises mostly proposals and voluntary actions related to the Farm to Fork Strategy, which remains non-legally binding. This suggests high relevance of multi-stakeholders' integrated efforts to promote tangible actions spurring a sustainable transition. Lastly, most measures are not directly related to the food sector, which could possibly underrepresent the efforts to build a resilient and sustainable FVC in Europe.

Keywords

Food value chain, sustainability, multi-stakeholders, food production, European policy, Eco-label, standard, decarbonisation, carbon footprint, GHG emissions

Presenter Profile

The presenter is a research associate at the Ibero-America Institute for Economic Research at University of Göttingen involved in the EU project ENOUGH.

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Introduction

In recent years, climate change has become a global challenge. Rising temperatures are triggering enormous disruptions in natural cycles worldwide (Naumann et al., 2018) and increasing social vulnerability (Otto et al., 2017). Meanwhile, international agreements have proposed guidelines, setting the path to a sustainable transformation. To succeed in doing this, governmental actions are at foremost priority as they can regulate markets, as well as the use of natural resources (Keskitalo and Kulyasova, 2009), and support innovation and development at a macroeconomic level. In addition, collective initiatives from multi-stakeholders open up a set of possibilities to propel sustainable pathways (Lambin and Thorlakson, 2018).

The food sector is central to sustainability debates, since a third of the global anthropogenic greenhouse gas (GHG) emissions originate along the food value chain (FVC) (Crippa et al., 2021). Moreover, it encompasses issues regarding food security, distribution and production to feed the growing world population. With the European Green Deal, the European Union (EU) approved stricter emission regulations and set forward ambitious measures to become a green economy. Under the Farm to Fork strategy, the food sector is especially addressed underscoring the need for a “fair, healthy and environmentally-friendly food system”. This is only achievable if the EU and neighbouring economies integrate public, industrial, and consumers sustainability-driven efforts (Schebesta and Candel, 2020).

At a global level, the Sustainable Development Goals (SDG) represent the main framework to guide society towards a sustainable transition, in which the food sector is central and directly addressed by SDG 2, 12, and 13. Despite political aspirations to sustainable FVC in Europe, the extent to which European policies and multi-stakeholders’ actions are conforming with the food-related SDG targets remains an open question. To give an answer to it, this paper systematically reviews European policies and regulations, financial mechanisms, and industrial and consumers initiatives that aim at achieving a sustainable FVC and link the initiatives’ priorities to the FVC-related SDG targets. The presented analysis allows us to identify potential synergies and political gaps in the EU green agenda, while offering some insights about how to improve integrated action to support sustainable FVC.

Methods

The methods consist of a systematic collection of EU policies and regulations and specific initiatives aiming to achieve sustainability in the FSC. The procedure is based on four steps: We start by defining the initiative categories, next setting the period covered, followed by the identifying the sources, and finally defining keywords. Five initiative categories are defined: (1) Policies and regulations, (2) food standards and ecolabels, (3) financial, (4) industrial and (5) consumer initiatives. More specifically, first EU policies collected are related to sustainability aspects in the food sector (1). Food standards and ecolabels aim at provide consumers with information about the carbon footprint of the food products available. Financial initiatives refer to public or private investments, whose main objective is to reduce environmental impacts in the FVC. Industry initiatives comprise all industry specific collective actions coming from associations, private or public actors, aiming to spur sustainability into their operations. Finally, consumer initiatives comprise collective efforts by consumer associations, NGOs, and civil associations to promote sustainable food consumption in Europe. The period covered goes mainly from 2000 until 2022, including also some important initiatives taken in the 1980s and 1990s.

We utilize the Google search engine to search for policies and initiatives, using the following keywords, among others: Policies and regulations (EU climate policies and regulations, EU food climate policies, GHG emission policies and regulations, EU food GHG policies and regulations); food standards and ecolabels (Ecolabel, standard, decarbonisation, carbon footprint, carbon emissions, GHG emissions); financial (financial decarbonization, sustainable fund, food sustainability fund, emission investments, reduce emissions food supply chain); Industry (sustainable industry, food industry initiative, industrial food supply chain, sustainable food industry, decarbonizing food industry); Consumer (food waste, food security, awareness, decarbonization, food supply, along with "consumers"). Additional sources consulted are the European Commission and the Climate Initiative Association to obtain a broader range of active policy measures, investment funds and projects active in climate action. Having the search concluded, we mapped the main policy priorities and initiatives to link them with food-related SDGs, namely SDG 2, 12, and 13.

Preliminary Results and remarks

We classified a total of 28 policies and regulations, 20 food standards and ecolabels, 27 financial mechanisms, 18 industrial and 13 consumer initiatives at the EU level that are related to stages of the FSC. In general, multi-stakeholders' initiatives and policies might have a broader character, leading to overlapping objectives. We identified eight underscoring political and eight stakeholders' priorities (Figure 1).

Figure 1: Linking priorities of policies and multi-stakeholders' initiatives to food-related SDG targets.

The EU political agenda has pointed to the need to reduce GHG emissions by supporting the use of renewable resources and alternative means of transport for logistics. Policies also capture the importance of border regulations to prevent carbon leakage into territories with lax climate measures. In parallel, climate change adaptation measures target especially food production and land use systems. The EU highlights the relevance of reporting carbon emissions as well as actions taken related to biodiversity preservation and other sustainability elements. Waste management and recycling are also acknowledged and important to reduce

GHGs and sustain biodiversity. In this case, regulations refer to the Farm to Fork strategy as setting a blueprint for sustainable FVC. Nevertheless, the strategy remains non-legally binding, presenting proposals still to be revised and approved. In fact, most priorities classified here comprise a list of proposals and voluntary actions depending on private efforts from firms, consumers, and local organizations.

Similarly, multi-stakeholders' initiatives prioritize emission reduction (not related to target 13.1 because it is not a political measure), sustainable food production, and waste management. Furthermore, stakeholders are strongly engaged in awareness and education, which potentially spur consumption patterns towards organic food and sustainable production. Stakeholders' initiatives also support Small and medium enterprises and research and development (and innovation) to the development of more competitive, smarter, and environmentally friendly companies.

All aforementioned priorities are, to some extent, synergic to SDG targets. Nevertheless, we spot political gaps in terms of a solid sustainable framework (12.1), which could be consolidated with the farm to fork strategy in the future. A concise plan to halt chemical management and pollution is needed (12.4), national policies to sustainable public procurement (12.7), and higher political emphasis on education and awareness (12.8). Furthermore, most measures are not directly or solely related to the food sector, which could possibly underrepresent the endeavor needed to build a resilient and sustainable food sector in Europe.

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The circular economy and sustainable development in European countries

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Extended Abstract

Due to the increasing consumption of resources and the growth of the world's population, the need for Sustainable Development (SD) that ensures the availability of resources is of major importance. In the face of climate change, natural disasters, continued increases in carbon emissions, global resource scarcity, high volatility, and the COVID-19 pandemic, achieving SD, already difficult for businesses and governments, has become even more challenging, raising the demand for a new business model (Ellen MacArthur Foundation 2014). Since Circular Economy (CE) could make compatible increase prosperity, growth and profitability with reducing dependence on virgin resources and energy (Ellen MacArthur Foundation 2015), CE is getting more and more prominent in the recent years (Stahel 2016; Moraga et al. 2019; Korhonen et al. 2018). The concept of CE is based on three principles: designing out waste and pollution, keeping products and materials in use at the highest possible value, and regenerating natural systems (Ellen MacArthur Foundation 2022). The implementation of these three principles leads to four sources of value:

1) Renewable resources or lasting resources
2) Reuse, sharing or liquid markets
3) Repairing, remanufacturing or longer life-cycles
4) Secondary raw materials, recycling and linked value chain

So, we aim to analyse the impact of four sources of value in CE on sustainable development. Specifically, we study their effect on the three dimensions of sustainable development: economic, social and environmental dimensions.

We use a panel data set covering the period from 2010 to 2019, we will conduct the empirical analysis for 24 EU member states (Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden) and the United Kingdom. As dependent variables we use three variables to measure the impact of CE on each dimension of SD: GDP per capita to measure economic impact, unemployment rate to measure social impact and GHG-Emissions per capita to measure environmental impact. We use one variable for each source of value of CE as independent variable, namely: factor recycling is the score of the following variables: recycling rate of municipal waste, circular material use rate, trade in recyclable raw materials; renewable resources is the share of

renewable energy in gross final energy consumption; factor repairing and remanufacturing is the score of the factor analysis of the following variables: number of enterprises per 100.000 inhabitants repairing machinery, number of enterprises per 100.000 inhabitants repairing computers and household goods, number of enterprises per 100.000 inhabitants repairing motor vehicles; sharing or co-ownership is the number of employees working in stores selling second-hand goods per 100.000 inhabitants. We also use eight control variables namely: innovation (R&D expenditures in % of GDP), education (% of people reached at least a tertiary degree), taxes (environmental taxes in % of GDP), eco innovation index, population density, sector composition (agriculture, industry, service).

Our research contributes to the study of the effects of CE on each dimension of sustainable development. We believe that we can fill the gap of the very few studies focusing on a broad range of benefits of the CE, while most articles focusing on specific aspects such as job creation potential (EC 2018) or economic growth (Ellen MacArthur Foundation 2015). Specially interesting is the three analyses in one single piece of paper that makes results comparable and increasing the scarce analyses of social impacts of CE (Korhonen et al. 2018; Schroeder et al. 2019; Padilla-Rivera et al. 2021). Indeed, our findings are going to be relevant for decision makers, managers and policy makers to apply environmental policy at national, European, international and global level to follow the transition to a circular economy. Also, our contribution sheds light on the indicators of CE.

Keywords

Circular economy, sustainable development, panel data

Dimensions in circular economy: a content analysis of current definitions

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Abstract

The idea of circular economy (CE) can be determined by the implementation of appropriate strategies designed in an environmentally friendly and sustainable way. The CE goals constitute a unifying element and at the same time a point of reorganization of public policies in the framework of European Green Deal. In this regard, a package of interventions should be incorporated to reduce the consumption of raw materials, to extend the life of products through maintenance and repair and to adopt the use of recyclable materials in product design while recovering the raw materials from waste streams. The present study aims to provide a comprehensive overview of research efforts documented by entities and researchers in CE through indexing 136 definitions, following Sullivan et al.'s (2018) methodology. Specifically, a thematic and content analysis is performed both with the Microsoft Excel software and the Leximancer™ software in order to delineate the relationships emerged among concepts. The goal is to present the possible ways of adopting the green principles that are governed by circularity by their nature reflecting the targets laid down in Union legislative acts. With this in mind, the CE proposal -according to the definitions- is to encourage initiatives and adopt more effective methods dedicated to waste elimination and recycling activities.

Keywords

Circular Economy, content analysis, Leximancer.

Presenter Profile

Mr. Vasileios Nikou is a Phd Candidate at the Department of Economics and Sustainable Development of Harokopio University with specialization in Macroeconomic Analysis of Circular Economy employing panel data. He studied Economics at the Department of Economic and Regional Development of Panteion University and holds a MSc degree in Applied Economics and Administration with specialization in Corruption and Economic growth and a MSc degree in Real Estate Economics with specialization in Spatial, Regional and Urban Planning at the Department of Economic and Regional Development of Panteion University.

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Price Linkages in major EU olive oil Markets

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Abstract

Olive oil is a huge part of the Mediterranean culture, economic activity and diet, thus constituting one of the most characteristic agricultural products for the Mediterranean regions. Despite several efforts by the European Commission to integrate the EU olive oi markets, there are still price dispersions which calls for further policy reforms to tackle market inefficiencies. Using monthly wholesale price data for the three principal olive oil markets in the EU, namely Spain, Italy and Greece, this study employs a series of unit root tests, linear and nonlinear cointegration and causality techniques as well as Asymmetric Error correction models to examine the long and short-run relationships between the countries considering possible asymmetries. The results indicate stable, long-run relationships between all three countries, with asymmetries being present between the pairs of Greece and Spain, and Italy and Spain. Spain is identified as the causal market which indicates that Spain is influencing price formation between the examined markets, and all three markets are found to be more sensitive to negative deviations from the equilibrium than positive deviations.

Keywords

Asymmetric Price transmission, market integration, virgin olive oil

Presenter Profile

Pamela Theofanous is a PhD Candidate in Land and Agribusiness Management Department at Harper Adams University. Her research focuses in investigating price relations between major olive oil markets with particular focus on Mediterranean markets. Her interest lies in price asymmetries analysis and reasons that hinder market integration. The aim of her research is to understand the functioning of the markets thus determining market imperfections and subsequently proposing policies to tackle any form of inefficiency.

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A multicriteria framework for measuring national energy performance

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Extended Abstract

The discussion over the climate crisis is rapidly increasing over the last years. More specifically, the extensive use of fossil fuels and the constant climate change, combined with a rise in energy demand have drawn the attention of governments worldwide (Ligus & Peternek, 2021). Under this context, all countries should focus their efforts on achieving sustainable development. However, this process is dependent on multiple factors. Besides the mineral resource's dependency, various socioeconomic and technological factors are affecting sustainable development, such as the social unevenness and economic recesses (WEC, 2020). Thus, the transition towards energy sustainability systems demands careful planning, that will allow the countries to maintain their socioeconomic status and simultaneously invest in alternative energy resources (Çelikbilek & Tüysüz, 2016).

The adoption of strategies that would enhance the efforts of achieving energy sustainability shape a multiple factor problem, which includes both qualitive and quantitative indicators (socioeconomic, technological, environmental etc.) should be taken into consideration (Siksnelyte et al., 2018). The aim of this research is to provide a novel framework that will classify countries based on their energy performance. Particularly, the countries are sorted into four energy performance categories:

- Excellent category (G4)
- Good category (G3)
- Sufficient category (G2)
- Insufficient category (G1)

Depending on what energy and environmental policies a country implements, it will be classified into one of the abovementioned categories. The assessment of the countries is accomplished with the use of the ELECTRE TRI, a multicriteria method that has successfully been applied to natural resources management problems. (Govindan and Jepsen, 2016)). The methodological framework of the proposed approach is presented in Figure 1.

Moreover, the criteria that were used in this research were based on the World Energy Trilemma Index and includes mainly energy related and socio-economic criteria: import dependence, diversity of electricity generation, energy storage, access to electricity, electricity prices for households, electricity prices for businesses, diesel prices, gas prices, final energy intensity, low carbon electricity generation, CO_2 emissions, macroeconomic stability, government effectiveness, innovation capability

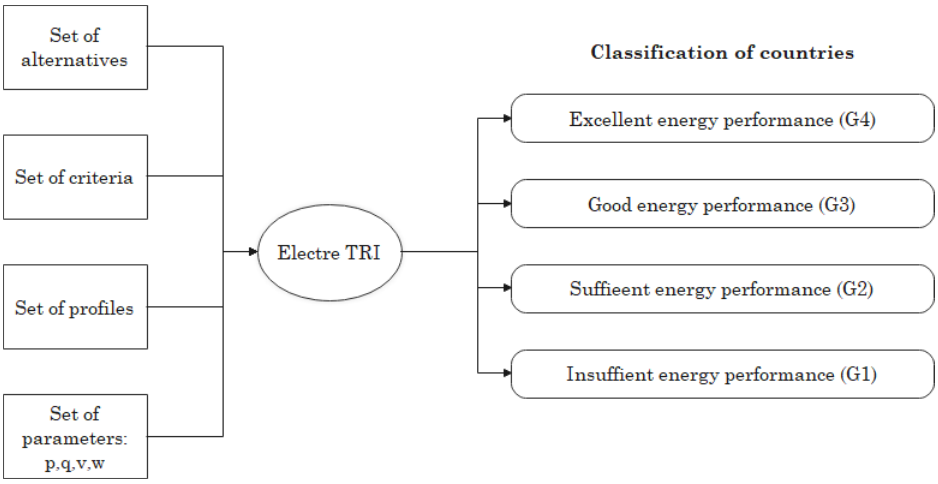

Figure 1: Methodological framework for countries classification

The main results of this study showed that the European countries are the best energy performers, while on the other hand the African countries should readjust their energy policies. Overall, 119 countries were evaluated. The advantage of this framework is that offers great flexibility, as the set of parameters may be adjusted according to the goals that each country wishes to accomplish, and indicates the effort that is needed, in order for a country to rank up a category and achieve better energy performance.

Keywords

Energy sustainability; Multicriteria Decision Analysis; ELECTRE-TRI; Energy Trilemma Index

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Presenter Profile

Stratos Kartsonakis is a PhD student at the Technical University of Greece. He received his bachelor diploma in Production Engineering and Management from the Technical University of Crete and has a Master of Science (MSc) in Technology and Operations Management from the University of Groningen. He has authored four papers and has given five presentations in international conferences. His research interests include multicriteria decision analysis, operational research, decision support systems, customer and employee evaluation and data analysis.

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Will Fiscal Expenditure for Agriculture Aggravates Water Pressure of Regional Grain Production? An Empirical Evidence From China

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Abstract

China's fiscal subsidies for agriculture is closely related to arable land area and grain production. Among them, insufficient subsidies for water security may exacerbate the regional water pressure of grain production. To explore this issue, from the perspective of sustainable utilization of agricultural water, we use entropy weight TOPSIS method and panel data of 31 provinces in Mainland China from 2003 to 2018 to empirically test the mechanism of the relationship between fiscal expenditure for agriculture and water pressure of grain production. And our findings are as follows. Firstly, by comparing the measurement results of fiscal expenditure for agriculture and water pressure of grain production in different regions, we found that there may be a specific relationship between them. In addition, the forecast results also show that the water pressure of grain production will continue to increase by 2030, with the northeast region and Huang-Huai-Hai region increasing the most, by 20.53% and 13.39%, respectively. Secondly, the results of basic regression showed that fiscal expenditure for agriculture aggravates grain production's water pressure, and this effect has a time lag. Both the split-sample and quantile tests showed that the above findings were robust. And fiscal expenditure for agriculture in northern China and major grain-producing areas strongly affect the water pressure of grain production. Thirdly, From the regression results of the moderating effect, we found that the better grain production technology can effectively restrain the aggravating impact of fiscal expenditure for agriculture on the water pressure of grain production. Finally, the regression results of the spatial econometric model showed a positive correlation between the water pressure of grain production in the neighbouring areas. The high and low water pressure of grain production appeared regional agglomeration phenomenon. And the fiscal expenditure for agriculture will exacerbate the water pressure of grain production in the area and neighbouring regions. This study innovatively explores the reasons for the increasing water pressure on food production from the perspective of fiscal expenditure for agriculture. It also provides reference suggestions for reducing water use pressure in food production and improving the financial support for agriculture subsidy policy.

Keywords

fiscal expenditure for agriculture; water pressure of grain production; grain production technology; crop sown area; spatial spillover effect

Presenter Profile

I am a PhD student from the College of Economics and Management, Huazhong Agricultural University. I am mainly engaged in research on agricultural technology and economics, and have published several related articles and have a certain degree of knowledge in this field. This study innovatively explores the reasons for the increasing water pressure on food production from the perspective of fiscal expenditure for agriculture. It also provides reference suggestions for reducing water use pressure in food production and improving the financial support for agriculture subsidy policy.

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Price transmission as an aspect of business sustainability: the case of the Lithuanian pork market

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Extended Abstract

Since the EU enlargement, national agricultural systems of Member States have survived remarkable structural transformations. Change in agricultural commodities' price behaviour was an important aspect that had a significant impact on the long-term business sustainability. This study investigates the Lithuanian case and focuses on the analysis of pork price transmission in order to explain the situation in pig farming. The selected methodological framework verifies main market malfunctioning problems, and results allow us to discuss the impact of price behaviour on business sustainability.

The research relies on logarithms of monthly prices collected by European Commission's Directorate-General for Agriculture and Rural Development and SE 'Agricultural Information and Rural Business Centre'. The period from January 2014 to May 2022 is investigated. This timeframe shows the stronger integration of the Lithuanian pork market into the EU market due to the deterioration of trade relations with Russia. The functioning of the Lithuanian pork market is investigated applying both vertical and horizontal price transmission analysis. Horizontal price transmission shows the inter-dependence of price changes between the Lithuanian market and six main pork producing countries (Denmark, Germany, Poland, Spain, France, and the Netherlands). Vertical price transmission analysis explains price passes between farmer, producer, and retailer along ham with bones and pork neck supply chains.

The methodological research framework includes multiple tests and models. First, the augmented Dickey-Fuller (1979) and the Phillips-Perron (1998) unit root tests are applied in order to classify data series into stationary and nonstationary. This step allows us to select an appropriate research model. Second, the short-run relations between prices are investigated using the Granger causality test (Granger, 1969) or Toda and Yamamoto (1995) specification of this test for nonstationary time series. Third, a Nonlinear Autoregressive Distributed Lag (NARDL) model (Shin et al., 2014) is employed to analyse the impact of positive and negative price changes on the development of the Lithuanian pork prices. Fourth, the presence of the long-run relations between price series of the selected NARDL model is investigated applying Bounds test. Finally, Vector Error Correction model is run for the price series that move together in the long run to estimate the speed of adjustment to equilibrium.

Results of the Granger causality tests between the selected EU countries and Lithuania suggest that the short-run inter-dependence of prices at farmer level depends on the country. Granger causality tests allow us to identify two groups of countries. Poland, Germany, Spain, and the Netherlands Granger cause prices on the Lithuanian market at 5.0% significance level, while test results for Denmark, France, and Latvia do not allow to reject the null hypothesis and

confirm one-way or two-way price causality. Thus, the EU pork market demonstrates a failure to ensure two-way price transmission and forms different groups of countries with the price setting inter-dependence in the short run.

According to the results of the NARDL modelling, the role of price fluctuations on the Polish market is critical for the price setting on the Lithuanian market. Bonds test for the level relationships confirms that NARDL (3,0,0) model includes price series that move together in the long run. NARDL (3,0,0) model shows that the long-run coefficients for positive and negative price changes are significant, while the error correction term is -0.92. The aforementioned results show that price development in Poland determines pork price changes in Lithuania. According to the results of Bounds test, price changes in the German market also have an impact on the price-setting mechanism of the Lithuanian pork market in the long run. NARDL (3,1,0) model for the Lithuanian and the German prices confirms the significance of the long-term coefficients for positive and negative price changes as well as the short-run coefficients for positive price changes. However, the speed of adjustment for the equilibrium Lithuania-Germany is lower, and the error correction term accounts for -0.75. Bounds test for the NARDL (3,3,2) model confirms the presence of the long-term relations for price series in Lithuania and the Netherlands. According to NARDL (3,3,2) model, the Lithuanian price development could be explained by long- and short-term coefficients for positive and negative price changes, while the speed of adjustment to the equilibrium is -0.62. Price changes in France also have an impact on the Lithuanian pork market in the long run, and the speed of adjustment is -0.38. NARDL (4,1,2) model shows that the development of prices could be explained by both long- and short-term coefficients for positive and negative price changes in France. Nevertheless, Bonds test for NARDL models for Denmark and Spain fails to confirm the long-run relations with the Lithuanian prices at the high significance level. These results could be linked to specific price developments and shocks that took place on that markets and challenge for the application of the more advanced models in order to investigate the long-run price relations.

In summary, the results of horizontal price transmission show that the price setting mechanism of the Lithuanian pork market is dependent on price development in main producing countries. This fact shows high vulnerability of local business due to insufficient control over the economic dimension of sustainability. The Lithuanian pig farming is forced to follow price changes in main producing countries even though those price developments do not allow to maintain the critical profit margins.

Vertical price transmission analysis along the chain of ham with bones shows that price changes run from farm to producer and from producer to retailer in the short run. The supply chain of pork neck demonstrates the same price setting mechanism. Thus, results of the Granger causality tests go in lines with the expected price behaviour. Bonds test for NARDL (3,1,0,4,0) model shows that in ham with bones chain prices at farm, producer and retail levels move together in the long run. However, the development of retail prices is better explained by lagged retail prices than positive and negative price changes at farm or producer level. Error correction term shows very slow adjustment to equilibrium and the corresponding significant speed of adjustment coefficient (-0.05). The case of the pork neck chain differs. Bonds test for NARDL (4,0,0,4,3) model shows the significant long-run coefficients of price changes for both farm and producer levels. The lagging short-term coefficients for positive price changes at farm level also contribute explaining the development of neck price development. However, the speed of adjustment to equilibrium is very low (-0.07). These results could be explained by price setting strategy at retail level. Both products demonstrate 'sticky' prices because retailers are seeking to stabilize price and ensure profit margins. The reluctant reaction to price decreases at producer and farm levels could violate the welfare of consumers and farmers.

In conclusion, the conducted research has identified important pork market malfunctioning issues that has a negative impact on pig farming business sustainability. The dependence on main producing countries challenges to overcome the gaps in technological development and productivity. However, disease outbreaks, new animal welfare requirements, and skyrocketing feed prices make investment environment less predictable and exacerbate the situation.

Keywords

Agriculture, market, pork, price transmission

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Presenter Profile

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Farmers risk attitude and the adoption of sustainable land management practices in Southeast Nigeria

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Extended Abstract

Despite the demonstrated benefits of sustainable land management (SLM) practices to increase soil fertility (Bishwakarma et al., 2015), reduce soil loss, and ultimately tackle land degradation (Lamichhane, 2013); the adoption of SLM remains (s)low especially among farmers in developing countries (Nkonya et al., 2016). There is growing evidence that socio-psychological factors (e.g risk attitude) – and not just socio-economic, institutional, and biophysical factors affect SLM adoption (Hardaker et al. 2015). For example, Hardaker et al. (2015) show that farmers' risk attitudes influence their decision on whether to adopt given new agricultural technologies or not. The risk in the adoption of SLM among smallholder farmers is brought by the need for additional resources to implement SLM. As suggested by Komarek et al. (2020), such a need for extra resources exposes farmers to financial risk through reliance on borrowed fund to finance the cost of implementing the given technology on their plot. In this light, this study aims to analyse the effect of farmers' risk attitudes and other potential control variables on SLM adoption with a case study of Southeast Nigerian farmers. The study also goes further to analyse the interactive effect of gender and risk attitude on SLM adoption. The relationship between gender and risk-taking behaviour has been documented in many empirical and experimental studies (Meemken et al., 2017; Magnan et al., 2020).

Methodology

This study was conducted in Southeast, Nigeria. A four-stage sampling technique comprising purposive sampling at the first stage and simple random sampling (at the subsequent stages) was employed to select 480 farmers for the study. Data for the study were collected using a semi-structured questionnaire that was designed in a computer-assisted personal interviewing format and administered using Qualtrics software. The questionnaire comprised questions on the socio-economic, institutional characteristics of the farmers as well as the characteristics of their main plot. There were also questions investigating farmers' self-reported risk attitude and their adoption of the three SLM practices of interest to this study– agroforestry, terracing, and crop residue management.

Measuring risk attitude

Farmers' risk attitude was measured using the psychometric approach of Dohmen et al. (2011). Following Dohmen et al., (2011), farmers were asked if they identify as individuals who generally are fully prepared to take risks based on a 5-point Likert scale ranging from 1-strongly disagree to 5-strongly agree. Farmers' selection of options 1 and 2 were categorized as risk-averse while farmers' selection of options 4 and 5 were considered risk lovers. Lastly, the selection of option 3 was classified as risk-neutral (Abbas et al., 2022). To ease analysis and interpretation, the farmers' risk attitude was transformed into a binary variable where 1= risk-averse farmers and otherwise 0.

Data analysis

The Multivariate Probit Model (MVP) was employed for the analysis of data. The MVP is helpful to account for the interdependent relationships between SLM practices adopted by the farmers (Kassie et al., 2013). The dependent variables in the model are the three sets of SLM practices, measured as 1= if the farmer adopts the SLM practice and 0 if otherwise. STATA software (version 15.0) was used for the data analysis.

Results and Discussion

The likelihood ratio test of the chi-square ($\chi 2$) (3) = 9.616 of the independence of the error terms is rejected at a five percent level of significance, confirming that the adoption of the SLM practices is not mutually independent and supports the use of the MVP model. The MVP result shows the factors (target and control variables) significantly influencing SLM adoption. For brevity's sake, the discussions, and implications of the paper focuses on the target variables (risk attitude and the interaction term of risk and gender).

Table 1 shows that the risk averse attitude of the farmers positively influenced their adoption of crop residue management ($p<0.05$) and terracing ($p<0.01$). This result is in contrast with the findings of Ali (2019), but in line with the findings of Crentsil et al. (2020) and Zeweld et al. (2019) that found that risk averse farmers are more likely to adopt agricultural technologies. Plausible explanation for the study finding could be that the risk averse farmers perceive these SLM as a risk-reducing technology and have a bigger necessity to protect themselves against potential risks (e.g. loss of crop due to erosion), thus, are more likely to adopt these SLM. This assertion is in line with Winsen et al. (2016) who noted that risk-averse farmers were more inclined to adopt ex-post curative measures when faced with risks while the risk-seeking farmers were more likely to adopt ex-ante risk management strategies. The adoption of crop residue management and terracing can be thought of as ex-post risk management tools in the study area. This is because erosion is a great challenge in the study area (Egbueri, Igwe and Unigwe, 2021) and farmers employ these SLM practices as a strategy for protecting the soil from erosion. Furthermore, the MVP result showed that the gender and risk interaction term were negatively related to the adoption of agroforestry ($P<0.1$) and terracing ($P<0.1$). This indicates that the slope of risk differs significantly for male farmers as compared to female farmers as it relates to the adoption of agroforestry and terracing.

Conclusion

The study showed that among other factors, farmers' risk aversion positively influenced the adoption of crop residue management and terracing, which are interpreted as risk management strategies. The empirical results of this study can provide helpful insights for policymakers in Nigeria to further improve the adoption of SLM practices among farmers.

Acknowledgement

We acknowledge the financial support from the Commonwealth Scholarship to conduct fieldwork for this study in Nigeria.

Table 1. Estimates of the Effect of Risk attitude on SLM Adoption

Variables	Agroforestry Coefficient	Crop residue Coefficient	Terracing Coefficient
Risk attitude (1= risk averse; otherwise= 0)	0.256	0.975**	1.565***
Risk attitude * gender	-1.264*	0.642	-1.476*
Gender of the farmer (1= male; otherwise= 0)	0.833**	-0.199	0.222
Membership (if farmer belongs to any village group = 1; otherwise= 0)	-0.117	0.058	0.252
Trust in Extension Agent services =1; otherwise= 0)	0.071	0.134	1.666**
Climate aware (if farmer is aware of climate change in last 5 years =1; otherwise= 0)	-0.536	-0.717	-0.702
Household size	-0.157***	0.013	0.137**
Years of schooling of farmer	0.023	0.004	0.074*
Marital status (if farmer is married= 1; otherwise=0)	1.039**	0.864**	0.463
Farm experience (number of years of farming)	0.017	0.004	0.009
Succession (If farmer thinks a family member will succeed the farm business= 1; 0 otherwise)	-0.172	0.052	0.510
Off farm employment (If the farmer is engaged in any non-farm work = 1; 0 otherwise)	-0.029	0.201	0.120
Livestock ownership = 1; 0 otherwise)	0.217	-0.297	0.109
Sell (If farmer sell any or part of their farm produce= 1; 0 otherwise)	1.534	0.988	1.065
Farmers reliance on traditional knowledge 1; otherwise = 0)	-0.292	-0.339	-0.604*
Farmer to farmer interaction	0.486*	-0.140	-0.054
Farm size in hectares	0.079	-0.130	-0.019
Erosion (if plot suffer erosion 1; otherwise, 0)	0.635**	0.066	0.113
Tenure document (If plot has an informal/formal tenure documentation= 1; otherwise=0)	0.797**	-1.334***	2.038***
Fplotmgt[a] (if plot is managed by a female)	0.513	0.653*	0.874*
Mplotmgt[a] (if plot is managed by a male)	0.230	0.842**	0.279
Plot slope (If farmer perceives the plot is located on a steep slope = 1; 0 otherwise)	0.463	-0.143	0.810**
Poorfertile[b] If farmer reports poor soil fertility = 1; otherwise =0)	0.611	0.494	-0.186
Goodfertile[b] (If farmer reports good soil fertility = 1; otherwise =0)	0.124	0.110	-0.163
Secure tenure (if farmer has tenure security over plot via inheritance or purchase)	0.701***	-0.139	0.811**
Plot fragmentation (number of plots owned by the farmer)	0.088	0.013	-0.034
Remittance (If the farmer received remittance in the last year = 1; 0 otherwise)	-0.890***	0.444*	-0.122
Credit constrained (if farmer is credit constrained = 1; otherwise=0)	-0.552	0.030	0.864***
Access to Agric. information via radio = 1; otherwise = 0)	0.069	0.183	-0.166
Extension access (number of extensions visits in the last year)	-0.131	0.122	-0.977*
Distance from farm to market in walking minutes	-0.004	0.008	0.007
constant	-2.089	-0.719	-6.032

[a]Note: Jointly managed plots is the reference category; [b]Note: Moderate fertile plots is the reference category; [c]Note: Imo state is the reference category

Statistical significance at $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

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Presenter Profile

Cynthia Olumba is an interdisciplinary Agri environmental social scientist working across a wide range of research areas in Environment, Food security and Sustainable development. Cynthia is currently a PhD student at the Newcastle University. Her PhD research is on the analysis of land degradation neutrality intervention in southeast Nigeria.

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Carbon offset due to using plastic pallets

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Abstract

Forests are recognized as man's main ally in the fight against global warming. It is coded into the popular consciousness that vegetation, through the process of photosynthesis, takes CO2 from the atmosphere and returns oxygen. The fact that forests, in addition to their function as 'green lungs', are a carbon store is not as widely realized. In our work, we show how changing from wooden to plastic pallets can help reducing emissions and improve the sequestration and storage potential of forests.

Keywords

circular economy, carbon footprint, CO2 sequestration, CO2 storage, wooden and plastic pallets, climate changes

The state and prospects of compound aquafeed production in Ukraine

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Abstract

The study shows the information about the development of the aquaculture sector in Ukraine. The leaders in the cultivation of marketable products in aquaculture in 2021 were Sumy, Cherkasy, Vinnitsa, Kirovohrad, Zhytomyr and Kyiv regions. Cyprinid fish species remain traditional objects of aquaculture: carp, white and bighead carp, their hybrids and grass carp. However, other species have recently been actively cultivated: rainbow trout, European catfish, pike, catfish, crucian carp, tench, and among sturgeons the most common are sterlet, Russian sturgeon, stellate sturgeon, beluga, bester, paddlefish, etc. The market of fish feed production is the following: 50% - for carp, 23%- sturgeons, 10% - catfish, 10% - salmon and 7% - other fish species. 42 % of aquaculture farms use compound feeds (local or foreign), 17 % - produce feeds themselves, 8 % - use grain (majority for carp feeding), 33 % - use grain by-products and oil cakes as fish feed ingredients. But the trend towards the gradual transition of many Ukrainian producers to intensive forms of aquaculture with the use of modern compound feed is becoming noticeable. Compound feeds for fish are being improved, adapted to new climatic conditions and fish breeds, and the field of feed sales is also developing. An important slogan of aquaculture: quality feed is the key to a successful business in aquaculture.

Keywords

Aquafeeds, Ukraine, aquaculture, fish farming, compound fish feeds

Presenter Profile

Dr. Liudmyla Fihurska is an Associate Professor of the department of grain and compound feed technologies, PhD in grain science. Her main expertise is in the field of animal feed technology and her research topic focused on animal feed, grain and food processing technologies, fish feed production, extrusion of fish feed, testing of feed manufacturing processes and animal feed.

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Introduction

In Ukraine aquaculture is one of the dynamic and profitable types of fish farming, which has a low barrier to entering this area of agribusiness and guarantees a quick return on investment and a sufficiently high profit. The main direction of fishery activity in the inland waters of Ukraine, which provides up to 70% of production in the total volume of freshwater fish catching and constitutes the main reserve for the further development of domestic aquaculture, is pond fish farming.

Methods

The material of the study was reports and scientific papers domestic and foreign scientists on the state of the fish farming industry in recent years. The data of the State Statistics Service of Ukraine, FAO reports, and analytical studies of the industry's activities were used. The study was carried out using monographic, structural-functional and abstract-logical methods. MS Excel was used for statistical data processing.

Results

Traditionally, the dominant role in pond fish farming in Ukraine is played by enterprises specializing in the cultivation of cyprinid fish species. In 2018, more than 4 thousand business entities carried out activities in aquaculture. They raised 20.2 thousand tons of marketable fish, including: cyprinids - 9.6 thousand tons, herbivorous - 7.8 thousand tons, catfish - 0.2 thousand tons, sturgeon - 0.1 thousand tons, salmon - 0.3 thousand tons, other species - 2.2 thousand tons. The leaders in the cultivation of marketable products in aquaculture last year were Sumy (2869 tons), Cherkasy (2520 tons), Vinnitsa (1934 tons), Kirovohrad (1369 tons), Zhytomyr (1216 tons) and Kyiv (1156 tons) regions [1-3].

Today in Ukraine, cyprinid fish species remain traditional objects of aquaculture: carp, white and bighead carp, their hybrids and grass carp. However, other species have recently been actively cultivated: rainbow trout, catfish, crucian carp, tench, and among sturgeons the most common are sterlet, Russian sturgeon, stellate sturgeon, beluga, bester, paddlefish, etc.

In Ukraine, there are fifteen farms engaged in the cultivation of sturgeon species. In 2018, more than 200 kg of black caviar were supplied to the domestic fish market and 67 kg of black caviar were sent for export. Sturgeon species are grown more by fish farms located in Zaporizhya, Cherkasy, Odesa, Chernivtsi and Kyiv regions. The development of sturgeon breeding in Ukraine in recent years is also associated with the development of recirculation aquaculture, to a lesser extent with the development of garden fish farming. The leading farms of Ukraine that are engaged in the cultivation of sturgeon species are: Osetr LLC (Kyiv region), NPSP Bester (Kyiv region), Chernihivrybhoz PJSC (Chernihiv region), Ukrainian Service Enterprise LLC (Kyiv region), PE "Fortuna-XXI" (Kyiv), LLC "Kindfish" (Kyiv region), "Odesa sturgeon complex" (Odesa region), Farm "Ishkhan" (Chernivtsi region), LLC "Oasis Bisan" (Mykolaiv region), GC "Aquasvit", LLC "Aqua Top" (Odesa), LLC "NPC "Forel" (Volyn region), SE "Irklievsky fish nursery" (Cherkasy region), LLC "Brig LTD" (Zaporizhya region), LLC " Biosila "(Kyiv), Olesya LLC (Kherson region).

The greatest results in the production of catfish species (the cultivation of European catfish prevails) were achieved by the Kirovograd, Kharkiv and Kyiv regions. In recent years, more and more clariid or marbled catfish are grown, which is the most common aquaculture object for recirculation system (recirculating water installations). It should also be noted that with the development of recirculating aquaculture, the production of tilapia is becoming more widespread [1-3].

Salmon breeding in Ukraine is represented mainly by the cultivation of rainbow trout. Traditionally, trout production is carried out in the Western regions, in the highlands. The most famous trout farms of the enterprise are SPC Trout (Volyn region), Farm Ishkhan (Chernivtsi region), FT Golubaya Niva (Transcarpathian region), PrJSC Transcarpathian Fish Processing Plant (Transcarpathian region), LLC Trion (Rivne region), PE "Kaskad" (Volyn region), FH "Galician source" (Lviv region).

The volume of salmon production fell by 13% compared to 2018. However, salmon make up only slightly more than 1% of the total number of farmed fish in Ukraine in 2019. This species was grown: - in pond farms - 34%; - in aquariums - 1%; – in swimming pools – 65%. It should be noted that the main object of Ukrainian salmon breeding is rainbow trout, and fish farms that grow trout are located in the western regions. At the same time, the data on the volume of trout feed used indicate not a drop in production volumes, but their growth, in 2019 - to almost 3 thousand tons.

The market of fish feed production is the following: 50% - for carp feeds, 23%- sturgeons feeds, 10% - catfish feeds, 10% - salmon feeds and 7% - feeds for other fish species [4]. Modern fish feed must consider both the economic and ecological components, i.e. the impact of feed production technologies, the origin of feed components, the impact of feed residues, and feed itself on the state of the environment in which the aquaculture facility is located, the impact on the environment bordering production facilities. Modern combined feeds are made considering the object of aquaculture, the breed, the stage of the life cycle of the fish and the purpose (mother stock or fattening).

An analysis of the cost structure of farmed fish allows us to say that the cost of feed is one of the largest cost items. Statistical data indicate that the amount of feed used by domestic fish farmers for fattening fish has been practically at the same level for a number of years. There is only the question of the quality of these feeds. A slight decrease in feed in aquaculture can be explained by the gradual transition of feeding from grain mixtures to better mixed feed. We also note an increase in the amount of feed for growing sturgeons; this direction can also be attributed to developing in Ukraine to a large extent due to the production of black caviar.

According the questionnaire 42 % of aquaculture farms use compound feeds (local or foreign), 17 % - produce feeds themselves, 8 % - use grain (majority for carp feeding), 33 % - use grain by-products and oil cakes as fish feed ingredients. But the trend towards the gradual transition of many Ukrainian producers to intensive forms of aquaculture with the use of modern compound feed is becoming noticeable [1-4].

LLC "Golden Food" is among the manufacturers of compound feed for facilities. The company produces fish feed under the trademark "Reucher Aqua Fish". Fiorma manufactures dry extruded complete feed for carp, catfish, salmon, and sturgeon fish species on modern high-tech equipment. LLC "Agro-Ros" has productivity to produce up to 150 tons of high-quality compound feeds for animal husbandry per day, which is over 50,000 tons of compound feed per a year from the perspective of up to 100,000 tons per year. (Tashlyk village, Smilyansky district, Cherkasy region, BUHLER equipment). PJSC "Vilshanka" (the full-system fish farm) produces granular feed for aquaculture not only for its own production, but also for sale subjects of aquaculture. Also, the world-famous manufacturer of fish feed - the Dutch company Skretting - built and commissioned a compound feed plant for aquaculture operating in Vinnytsia. One of the directions of its production is carp feeds.

Conclusion

Aquaculture is an important sector of the economy and a source of income for the country's population. In Ukraine, the fish feed market is just forming. Imported products are represented on this market, and domestic analogues that compete with imports are beginning to appear. Compound feeds for fish are being improved, adapted to new climatic conditions and fish breeds, and the field of feed sales is also developing. It is worth noting an important slogan of aquaculture: quality feed is the key to a successful business in aquaculture.

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Adoption of Coping Strategies to Rabbit Haemorrhagic Disease Outbreak by Rabbit Farmers in Kwara State, Nigeria

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Abstract

Rabbit production is increasingly becoming a source of livelihood to many households in Nigeria. Unfortunately, a recent incidence of Rabbit Hemorrhagic Disease (RHD), which is a virulent and rapidly spreading disease of rabbits adversely affected the Nigerian rabbit industry and caused significant economic loss to farmers. Hence, this study assessed the coping strategies adopted by rabbit farmers as response to the RHD outbreak in the study area. A snowball sampling technique was adopted for selecting 120 affected rabbit farmers from whom data utilized for the study were collected using structured questionnaire. The obtained data were analysed using descriptive statistics to describe the rabbit farmers based on their socioeconomic characteristics and the different coping strategies adopted; and Multivariate Probit (MVP) Regression Model to determine the factors influencing the rabbit farmersˈ adoption of coping strategies. The result from the MVP analysis revealed that age of the farmer, size of household, membership of cooperative, extension contacts, amount of credit accessed, income per rabbit production cycle, and income from other sources significantly influenced rabbit farmersˈ adoption of coping strategies. It is, therefore, recommended that the farmers should join farming cooperatives so that they can have access to useful resources and relevant information that can help them cope with the risks involved in the business. In addition, extension education and outreach should be frequently provided to the rabbit farmers to avail them of advisory services that can help with mitigating the impact of the risks involved in the business.

Keywords

Coping strategies, disease, economic loss, multivariate probit regression, rabbit farmers

Presenter Profile

Muhammad Adeiza Bello recently completed his bachelorˈs programme as the top student in his cohort with a First-Class Honors in Agricultural Economics and Farm Management at the University of Ilorin. During his undergraduate studies, he developed a strong interest in development research and explored research frontiers in the food production system. His current research interest lies in agricultural production economics and livelihood studies in rural economies.

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Introduction

Agriculture plays a major role in ensuring food and nutrition security in any nation. A nation that is unable to meet its food requirements is at the mercy of other countries that are food self-sufficient. According to Food and Agricultural Organization (FAO) (2020), about 690 million people are undernourished globally in 2019, which increased by nearly 10% from 2014. FAO (2013) report also supported the findings of Conway (2012) and Swaminathan (2012) that the larger proportion of people dwelling in developing countries are food insecure. With the rapidly growing human population of developing countries, the pursuit of alternative protein sources to meet the nutritional needs of the population becomes imperative. Economic indices indicate that the food requirement will continue to increase as this trend in population increases, and consequently more people need to be provided with food. In order to optimize food production and meet the increasing protein requirement, viable options need to be explored. Options available include considering livestock species that have not been fully explored to meet the meat demand within the affected countries. Rapidly growing livestocks such as rabbits possess several characteristics that endeared it as among the category of underutilized livestock species in developing countries that could be the most suitable and sustainable means of producing high-quality meat (protein) to combat animal protein shortage in the diet of people in developing economy (Nworgu and Hammed, 2009; Okorie, 2011).

In recent years, there has been an increasing demand for rabbit meat and a gradual intensification of rabbit production in Nigeria. This can be ascribed to the high nutritional benefit of rabbit meat and several other potentials associated with rabbit production. Rabbits have enormous potential and beneficial characteristics, according to Mutsami and Karl (2020), including better feed usage, rapid growth, fewer input requirements, high prolificacy, and lucrative output products such as meat, manure, pelt, and urine. Onebunne (2013) reported that rabbit is a lucrative enterprise that has a high chance of recovering the initial investment, and gives early return on investment. In addition to these, rabbit meat has fine quality, tender characteristics, and immense nutritional value which makes it a suitable meat for hypertensive patients (Ozor and Madukwe, 2005; Okorie, 2011). Recently, rabbit urine and faeces from rabbit production have become more popular as a good source of pesticide and manure among vegetable farmers in Nigeria (AllAfrica, 2021). Conclusively, rabbit production in Nigeria provides economic benefits and opportunities that remain untapped. With nutritional deficiency posing a problem in Nigeria, rabbit production could make a significant contribution to human welfare to fill the nutritional gap and income generation.

Despite the prospects in the production of rabbits, there are, however, some factors limiting the production of rabbits. Previous studies have identified disease incidence as one of the major constraints militating against rabbit production (Chah et al., 2018; Aminu et al., 2020). Rabbits are susceptible to lethal viral, bacterial, and parasitic diseases that drastically affect their production. Common rabbit diseases are diarrhoea, coccidiosis, ear canker, conjunctivitis, and pneumonia (Commercial Livestock Production Guide Series, nd). These diseases can make rabbit production become unprofitable. For instance, coccidiosis is one of the major causes of losses to farmers (Okumu et al., 2015). According to Elshahawy *et al*., (2016), mange which is a disease caused by mites has become a major limitation in rabbit production. It causes rabbits to lose healthy body condition, and develop stunted growth, which subsequently leads to economic losses in rabbit farms (Chah *et al.,* 2018; Sharun *et al.,* 2019).

Recently, the Nigerian rabbit industry is being threatened by a more fatal disease known as Rabbit Haemorrhagic Disease (RHD), causing severe economic losses to rabbit farmers. The disease is a virulent form of viral hepatitis affecting rabbits, with a mortality rate of 70% to 100% in adults. (Capucci *et al.,* 2017). Three strains of medical significance have been currently identified and they are RHDV, RHDVa, and RHDV2. RHDV2 is thought to have first appeared in Europe about 2010 and has since spread to many countries (Akintayo *et al.,* 2021). Although outbreaks of RHD have been reported in a number of West African countries since the late 1980s (Ambagala *et al.,* 1999), the first officially identified case in Nigeria was however reported in June 2020 in Ilorin, Kwara State, among commercially raised rabbits under intensive management with a total of 17,415 rabbit mortalities recorded from about 19,474 susceptible cases from 74 confirmed outbreaks in different states of Nigeria including Ekiti, Oyo, Kwara and Lagos as of October, 27th, 2020 (Daodu *et al.,* 2021; Folajimi *et al.,* 2020). According to Daodu et al., (2021) the disease was likely brought into the country through the importation of rabbits infected by the virus or contaminated materials. In Nigeria, no reliable statistics or data exists to describe the rabbit industry and with the level of government involvement, rapid response and support to diseases outbreak may not be provided. Given that vaccination of rabbits against RHD is currently not a practice among rabbit farmers in Nigeria (Daodu et al.,) and in light of the foregoing situation, coping strategies are necessary to mitigate the production risk and economic losses associated with the disease. Based on the researchersˈ knowledge, no research has yet been conducted to assess the coping responses of rabbit farmers to RHD. Therefore, it is necessary to carry out this study to specifically; examine the socio-economic characteristics of the rabbit producers in the study area, identify the major coping strategies adopted as response to RHD by the rabbit farmers in the study area, and identify the determinants of rabbit farmers' adoption of coping strategies to RHD in the study area.

Methodology

Study location

The research study was conducted in Kwara State, Nigeria. The state is known to be the border between northern and southern Nigeria. It is bordered in the North by Niger State, in the South by Oyo, Ekiti, and Osun State, in the East by Kogi State, and in the West by Benin Republic with which it shares an international border. The state has sixteen (16) Local Government Areas (LGAs), which are divided into four (4) agricultural zones – A, B, C, and D, by the state’s Agricultural Development Project (ADP). The primary economic activity of the people in the state is agriculture and it is predominantly practiced by the rural population.

Sampling Procedure

The target population for this study included all rabbit farmers in Kwara State. We adopted a snowball sampling procedure to identify 120 rabbit farmers whose farms were affected by the RHD. The study utilized primary data collected through personal interviews with the respondents using a structured questionnaire.

Analytical Framework

The study employed a combination of tools including descriptive statistics and Multivariate Probit (MVP) regression technique for analysis.

Descriptive Statistics

Descriptive statistics was utilized to describe the socioeconomic factors of the respondents and the coping strategies adopted as response to the RHD outbreak by the rabbit farmers.

Multivariate Probit Regression Model

The MVP regression model was adopted to examine the factors influencing the rabbit farmers' adoption of the coping strategies to RHD. This model is particularly useful when the individuals' decisions are jointly correlated. In the study, the coping strategies are not mutually exclusive; considering the tendency of simultaneously using more than a coping strategy and the possibility of correlation in the adoption of these strategies. Hence, we adopted the Multivariate Probit model allowing for the possible correlation in the decision to adopt the coping strategies.

The MVP model can be implicitly specified as:

$Y_{ij} = X_{ij}\ \beta_j + \varepsilon_{ij}$

Y_{ij} is the dependent variable, representing the coping strategies alternatives faced by the i^{th} farmer. In the model specification, Y_j is a binary variable that assumes the possibility of only two outcomes (0 for non-adoption and 1 for adoption) such that '**j**' represents the number of each coping strategy i.e., j = 1…..m (for the study, m =9).

X'_{ij} represent the vector of explanatory variables influencing the coping strategies decision;

β_j represents the vector of the parameters to be estimated; and

ε_{ij} represents the random error term.

Therefore, the variables are specified as:

Y_j = Adoption of coping strategy '**j**' (1 if rabbit farmer adopts strategy '**j**', 0 if otherwise); and

X_1 = Age of rabbit farmer (years);

X_2 = Size of household (number of individuals in the household);

X_3 = Educational attainment (highest level of education attained by farmer);

X_4 = Years of rabbit farming experience;

X_5 = Membership of farming cooperatives (1 if member, 0 if otherwise);

X_6 = Amount of credit borrowed from all sources for production (in Naira);

X_7 = Stock size (number of rabbits)

X_8 = Number of extension visits in the last one year

X_9 = Rabbit production income per cycle (in Naira)

X_{10} = Monthly income from other sources (in Naira)

Results and Discussion

Socioeconomic characteristics of the Rabbit Farmers

Table 1 presents the socioeconomic characteristics of the rabbit farmers. The rabbit farmers have a mean age of 38 years and the majority (62.5%) are within the age range of 20 – 39 years. This indicates that rabbit production is predominantly practiced by younger people in the study location. Younger farmers are expected to be capable of effectively carrying out the rigors involved in rabbit production. This finding is supported by Sofoluwe *et al*., (2011) who posited that younger farmers because of their longer planning horizon, possess more knowledge, adopt better farming methods, and maybe more willing to take risks. The majority (91.7%) of the rabbit farmers are male, indicating that men are more actively engaged in rabbit farming business than women. According to Alonge *et al.,* (2016), men traditionally dominate the production of livestock, ownership of more valuable stock, and the decision-making in the livestock production system. The majority (77.5%) of the rabbit farmers are married, indicating that married people are more involved in the business of rabbit production in the study area. The result also showed that the farmers have a mean household size of 4. Household size is assumed to represent labour input to the farm, thus farming household whose size is greater than or equal to the mean household size has more likelihood of being inclined to divert family labour into the activities involved in the adoption of the coping strategies. A larger proportion (83.3%) of the rabbit farmers had tertiary education while 16.7% had secondary education. This shows that the majority of the rabbit farmers in the study area have a high level of literacy. According to Jirgi (2013) and Osundu *et al*., (2015), education improves human capital and enhances farmersˈ ability to make effective managerial decisions including the adoption of appropriate risk management strategies. The majority (68.3%) of the rabbit farmers are primarily engaged in non-farming occupations. The result further shows that the majority (60.8%) of the rabbit farmers are salary earners, 27.5% are involved in no other occupation than farming and 11.5 % are artisans. This indicates that most farmers are engaged in rabbit production as a subsidiary income source. The rabbit farmers have an average experience of 4 years in rabbit production. This indicates that most of the farmers are relatively new in the business and this could negatively influence their abilities to make effective managerial decisions. The result shows that the rabbit farmers have an average stock size of 116. This may be an indication that the rabbit farmers are engaged in rabbit production for commercial purpose. This is likely to influence their choice of coping strategies as farmers may be inclined to ensure the continuity of the rabbit farming business. The result also shows that the majority (81.7%) are non-members of farmers’ cooperatives. Membership of farmersˈ cooperative influences the adoption of coping strategies as it facilitates the exchange of information and ideas between farmers and also serve as an important source of capital for farmers. Nto *et al.,* (2011) and Ayinde *et al.,* (2008) in their studies detailed the importance of cooperative societies in credit access, education, and risk management. The result further shows that the majority (90%) of the rabbit farmers had no contact at all with extension agents. This indicates that the rabbit farmers received fair to poor extension services. Obinne (1996) argued that farmers who are frequently in contact with extension agents are more able to obtain agricultural information and have higher tendency to adopt improved livestock management practices. Furthermore, a mean credit of ₦51,350 was obtained by only 30% of the farmers. The low amount of credit accessed may be as a result of the strict conditions and lending procedures attached to borrowing credit by especially by small-scale farmers from formal financial institutions, as corroborated by Ukwuaba *et al.,* (2021).

Table 1: Socio-economic Characteristics of Rabbit Farmers (n = 120)

Characteristics	Frequency	Percentage	Mean
Age			
20 – 39	75	62.5	38
40 – 59	43	35.8	
≥60	2	1.7	
Total	120	**100**	
Gender			
Male	110	91.7	
Female	10	8.3	
Total	**120**	**100**	
Marital Status			
Single	26	21.7	
Married	93	77.5	
Separated	1	0.8	
Total	**120**	**100**	
Size of household			4.13
1 – 3	40	33.3	
4 – 6	68	56.7	
7 – 9	12	10.0	
Total	**120**	**100**	
Educational attainment			
Secondary Education	20	16.7	
Tertiary Education	100	83.3	
Total	**120**	**100**	
Primary Occupation			
Farming	38	31.7	
Non- farming	62	68.3	
Total	**120**	**100**	
Other Major Occupation			
None	33	27.5	
Artisan	14	11.5	
Salaried Employment	73	60.8	
Total	**120**	**100**	
Rabbit Farming Experience			4
<5	101	84.2	
5 – 9	16	13.3	
≥10	3	2.5	
Total	**120**	**100**	
Stock Size (number of rabbits)			115.88
≤100	55	45.8	
101 – 200	55	45.8	
>200	10	8.3	
Total	**120**	**100**	
Membership of Cooperative			
Yes	22	18.3	
No	98	81.7	
Total	**120**	**100**	
Number of Extension Contact			
No contact	108	90	
1 – 2	12	10	
Total	**120**	**100**	
Accessed Credit			
Yes	36	30	
No	84	70	
Total	**120**	**100**	

Amount of Credit Accessed (₦)			51350
<100000	99	82.5	
100000 – 199999	11	9.2	
200000 – 299999	4	3.3	
300000 – 399999	2	1.7	
≥400000	4	3.3	
Total	**120**	**100**	
Rabbit Production Income per cycle (₦)			224458.33
<100000	1	8.0	
100000 – 199999	60	50.0	
200000 – 299999	32	26.7	
300000 – 399999	17	14.2	
400000 – 499999	5	4.2	
500000 – 599999	3	2.5	
≥600000	2	1.7	
Total	**120**	**100**	
Income from Other Sources (₦)			152781.53
<200000	95	79.2	
200000 – 399999	16	13.3	
400000 – 599999	2	1.7	
600000 – 799999	3	2.5	
800000 – 999999	1	0.8	
≥1000000	3	2.5	
Total	**120**	**100**	

Identification of Coping Strategies Adopted by Rabbit Farmers as Response to RHD

Table 2 presents the distribution of the rabbit farmers by the coping strategies adopted as response to RHD. All (100%) of the rabbit farmers adopted biosecurity measures, restocking from reputable sources, proper water and feed management, and cage relaxation as ex-post coping strategies to prevent the reoccurrence of the disease. The possible reason for this can be attributed to the highly contagious nature of the diseases and the significant losses due to mortality resulting from the disease. On the other hand, only a smaller proportion (47.5%) of the farmers adopted veterinary services. This can be attributed to the perception of the farmers on the use of the services of veterinarian. Interview with the rabbit farmers revealed that the majority of the farmers attach low importance to the services of a veterinarian as a coping strategy for mitigating losses on the farm. Also, the majority (85.83%) of the rabbit farmers adopted personal savings and reserves as a coping strategy while 8.33%, 11.7%, and 21.67% of the rabbit farmers adopted diversification of enterprise, sales of assets, and credit borrowing respectively as ex-post coping strategies to RHD. This may be an indication that the farmers depend majorly on personal savings and reserves as a source of finance for farm operations.

Table 2: Distribution of Rabbit farmers by Coping Strategies Adopted (n=120)

S/N	Coping Strategies	Frequency	Percentage
1	Veterinary Services	57	47.5
2	Biosecurity Measures	120	100
3	Restocking from reputable sources	120	100
4	Proper water and feed management	120	100
5	Temporary closure or cage relaxation	120	100
6	Personal savings and reserve	103	85.83
7	Sales of assets	14	11.67
8	Credit borrowing	26	21.67
9	Diversification of enterprise	10	8.33

Source: Field Survey, 2021

Factors Influencing Rabbit Farmers' Adoption of Coping Strategies to RHD

Table 3 presents the factor influencing rabbit farmers' adoption of coping strategies of different coping strategies. The adopted strategies used in the MVP estimate include: personal savings and reserve, veterinary service, credit borrowing, sales of assets, and diversification of enterprise. Other strategies including biosecurity measures, restocking from reputable sources, proper water and feed management, and temporary closure were dropped as a result of non-variation of observation.

The result of the MVP estimate for the determinants of the adoption of coping strategies to RHD is shown in Table 3. The use of MVP model in evaluating the factors influencing the adoption of different coping strategies is justified given that the null hypothesis for the test of independence in the model is rejected, such that, the likelihood ratio test (Log likelihood = –214.12133, Prob > chi2 = 0.0084) of independence is significant at 1% indicating the presence of complementarity among the adopted coping strategies. The coefficients of pairwise correlation (Rho) (Table 3) also indicate a positive correlation between six of the pairs and a negative correlation between four of the pairs. This confirms that the sets of coping strategies are largely complementary.

The result revealed that the coefficient of the amount of credit accessed is negative and significant at 10% level in influencing the adoption of "personal savings and reserve." This implies that the farmers are less inclined to adopt the usage of personal savings and reserves as the amount of credit accessed by the farmers increases. This may be because the farmers do not have enough savings or money in their reserve and thus are inclined to borrow as a means to increase their capacity to cope. The coefficient of other income per production cycle is positively associated personal savings and reserves and statistically significant at 10% level. This implies that as farmers are more likely to adopt the usage of personal savings and reserves as a coping strategy against RHD as their income from other sources increases. This may be because smallholder farmers with higher income level have higher propensity to tolerate and cope with risks.

The result also revealed that the coefficient of age is positive and significantly influenced the usage of "veterinary service" at 10% as coping strategy by farmers. This translates that the farmers have higher tendency to adopt the usage of veterinary service as coping strategy as they grow older. This may be because older farmers are more likely to be risk-averse as seen in Akinola (2014), and as a result are more likely to take one the services of veterinary experts as a coping measure to protect their investment and prevent possible reoccurrence of the disease. This result contradicts the finding of Salau (2019) that older farmers are less inclined to adopt veterinary services as compared to younger farmers. The coefficient of membership of cooperative is positive and significant at 5% in influencing the adoption of "veterinary service" as coping strategy by farmers. This translates that, farmers who are members of cooperatives have more tendency to adopt the usage of veterinary service as a coping strategy to RHD. This can be attributed to the fact that membership of cooperative provides farmers with platform for gaining access to credit and exchanging innovative ideas for improving managerial decisions for farm operations. This result is in consonance with Salau (2019) that reported a significant and positive relationship between the adoption of veterinary service and membership of social organization. The coefficient of the amount of credit accessed is positively associated with veterinary services and significant at 10%. This infers that as the amount of credit accessed by farmers increases, the propensity to use veterinary service as coping strategy increases. This is because access to credit enhances the capacity of farmers to finance farm operations including the use of veterinary services. The coefficient of extension contact is positively associated with veterinary services and statistically significant at 5%. This infers that the farmers have higher tendency to adopt the use of veterinary services as coping strategy as the frequency of extension contact increases. This may be because farmers that are frequently contacted by extension agents have higher likelihood of adopting livestock health innovations and as a result see the need to use veterinary services as a coping strategy against animal health risk. This result is in line with the findings of Salau (2019).

The result further revealed that the coefficient of size of household is negative and significantly in influenced the adoption of "credit borrowing" at 10% as coping strategy by farmers. This infers that the farmers are less inclined to adopt the usage of credit borrowing as coping strategy as household size increases. The possible reason for this may be because larger household size might translate to more labour supply which might subsequently lead to larger agricultural production and higher household income, thus reducing the propensity to adopt borrowing credit as a coping strategy. The coefficient of the amount of credit accessed is positively and significantly associated with credit borrowing at 1% level. The implication of this is that the adoption of credit borrowing as coping strategy increases as farmers borrow more credit. The coefficient of income per production cycle is negatively and significantly associated with credit borrowing at 10%. This infers that the farmers are less inclined to adopt credit borrowing as a coping strategy as the income from rabbit production per cycle increases. The possible reason for this may be that the farmers earning higher income from rabbit production might have enough financial resources at their disposal, and as a result, are not motivated to borrow credit.

The result also revealed that the coefficient of stock size is significant at 10% and positively influenced the adoption of selling assets as a coping strategy by the farmers. This implies that as the size of stock increases, the farmers become more inclined to adopt sales of assets as coping strategy. The possible reason for this may be that farmers with larger size of stock have the tendency to possess more productive assets and as a result might adopt selling part of these assets.

The result revealed that the coefficient for the size of household is significant at 5% and positively influenced the adoption of diversification as coping strategy by the farmers. This infers that the farmers have more tendency to adopt diversification of enterprise as their household size increases. Increasing household size serves as an incentive for farmers to diversify for generating additional income to mitigate the welfare impact of the disease on the household.

Table 3: Estimates of the MVP for Determinants of Rabbit Farmers' Adoption of Coping Strategies

Variables	**Personal savings & reserve**	**Veterinary service**	**Credit borrowing**	**Sales of assets**	**Diversification**
Age	– 0.026 (0.029)	0.039* (0.022)	0.040 (0.036)	– 0.0201 (0.030)	– 0.061 (0.042)
Household Size	0.103 (0.131)	– 0.002 (0.093)	– 0.258* (0.149)	0.086 (0.134)	0.334** (0.140)
Educational Level	– 0.482 (0.634)	0.469 (0.472)	0.122 (0.604)	4.074 (180.159)	– 0.721 (0.715)
Years of Experience	0.066 (0.079)	– 0.092 (0.063)	0.067 (0.066)	0.076 (0.080)	– 0.009 (0.104)
Membership of Cooperatives	– 0.258 (0.462)	0.838** (0.379)	0.632 (0.531)	– 0.214 (0.495)	0.780 (0.551)
Amount of Credit accessed	– 2.31e-06* (1.24e-06)	1.92e-06* (1.17e-06)	8.07e-06*** (2.01e-06)	4.55e-07 (1.18e-06)	2.40e-06 (1.61e-06)
Extension Contact	–0.140 (0.362)	0.954** (0.454)	– 0.080 (0.418)	– 0.978 (0.676)	–0.684 (0.840)
Income per Production Cycle	3.10e-07 (7.52e-07)	– 1.15e-07 (6.14e-07)	–4.50e-06* (2.49e-06)	8.92e-07 (5.93e-07)	– 1.07e-06 (3.09e-06)
Income from Other Sources	2.81e-06* (1.68-06)	6.07e-08 (2.20e-07)	– 7.79e-07 (1.55e-06)	– 6.17e-07 (5.84e-07)	– 1.31e-06 (1.43e-06)
Stock Size	– 0.0002 (0.0040)	– 0.0008 (0.0029)	0.0001 (0.0045)	0.006* (0.004)	– 0.0004 (0.0061)
Constant	2.496* (1.484)	– 2.816** (1.219)	– 1.368 (1.308)	– 13.983 540.475	1.616 (1.355)
	Rho1	**Rho2**	**Rho3**	**Rho4**	**Rho5**
Rho2	– 0.19				
Rho3	– 0.03	0.03			
Rho4	0.06	0.02	– 0.15		
Rho5	0.15	0.31	– 0.30	0.04	
LR test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0 *Number of observations = 120 chi2(10) = 5.94358 Prob > chi2 = 0.0084*					

Conclusion

The purpose of this study is to examine the coping options explored by the affected farmers and the determinants of the farmers' decision to adopt the coping strategies as a response to the RHD outbreak. Findings from the study revealed biosecurity measures, restocking from reputable sources, proper water and feed management, temporary closure or cage relaxation, and usage of personal savings and reserve as the most common coping strategies adopted by the farmers include. The study further revealed a jointness or interdependence in the decision to use any of the strategies. Alternatively, the tendency of using one strategy influenced the tendency of using another strategy. The implication of this is that there is synergy in the decision to use any two or more of the coping strategies. Among the socio-economic variables, age is an important determinant of the adoption of veterinary service. Older farmers have higher tendency to adopt the usage of veterinary service as coping strategy. Farmers with larger household size showed less tendency to adopt credit borrowing but higher tendency to adopt diversification of enterprise. Membership of cooperatives is significantly positively correlated to the adoption of veterinary services. Higher amount of credit accessed by the farmers reduced the adoption of personal savings and reserves, and increased the adoption of veterinary services and credit borrowing as coping strategies. Extension contact significantly and positively influenced the adoption of veterinary service as a coping strategy. Income per production cycle statistically and negatively influenced the adoption of credit borrowing while income from other sources statistically and positively influenced the adoption of personal savings and reserves as coping strategy to RHD. The present study is only limited to the farmers decision to adopt the coping strategies and does not reflect the effectiveness of the strategies adopted. Nonetheless, the study framework may be useful for future research investigating the effectiveness of the coping strategies adopted as response to disease outbreak in the study area and other regions in the country. However, the study provided some recommendations. Given that extension contact is significant in the adoption of veterinary services, extension services should be adequately provided to the rabbit farmers in the study area. This will help to improve their managerial abilities and provide them with relevant information and advisory services that can help them mitigate the impact of risks involved in the business. Providing these extension services can also motivate more farmers to consult the services of veterinary experts as a coping strategy for mitigating farm losses resulting from disease incidence. Farmers are also advised to diversify their income sources as this can be useful in creating financial reserves or savings for bad periods. Additionally, Government and relevant stakeholders should make RHD vaccines available in the country at a subsidized price to farmers in order to mitigate the impact of this disease on the farmers should there be future outbreaks.

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Relationship between economic development & environmental sustainability in selected European countries

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Extended Abstract

This paper aims to examine the relationship between economic development and environmental sustainability in European countries. The environmental indicators used are greenhouse gas emissions, air pollution (PM2.5) and the Global Sustainable Competitiveness Index. Furthermore, the effects of trade openness, urbanization, and renewable energy consumption on environmental sustainability are researched. In order to reach this objective, panel data from 32 European nations in a timeframe from 2010-2021 was collected. This data was analysed using panel unit root tests, panel cross-sectional dependence tests, panel cointegration methods, and panel causality tests. The results confirm a long term cointegration between GDP and the environmental indicators. Furthermore, they also confirm a cointegration between trade openness, urbanization, and renewable energy consumption on these indicators.

European economies have been growing for a long time, however economic growth often comes with a cost on the environment. Economies use up natural resources and pollute the environment to grow, this threatens the ecological environment. In the long run this undermines the foundation upon the economy is build. This could therefore affect the long-term sustainable growth of an economy (Le et al., 2018).

The effects of climate change are already visible in Europe, as in the past years multiple temperature records have been broken (Pannet, Hassan and Samenow, 2022). Furthermore, climate change effects economies as rainfall patterns increase, frequency of droughts increases and agricultural outputs are affected. Furthermore, it can also impact human lives, as people will be displaced from their original habitats and their health will be affected because of higher levels of pollution (Vajpeyi, 2013).

The main objective of this study is to research the relationship between economic development and environmental sustainability in European countries and whether these can be achieved simultaneously. The study empirically examines the connection between GDP per capita and GHG emission, air quality, and the global sustainable competitiveness index. Furthermore, it researched the influence of trade openness, urbanization, and renewable energy consumption on these earlier named variables.

The data for these seven variables has been collected from multiple sources, such as Eurostat (2022), Worldbank (2022), and OECD statistics (2020). Data has been collected for 32 countries, which include the EU-27 countries and Iceland, Norway, Serbia, Switzerland, and The United Kingdom. The time-frame of the data set ranges from 2010 to 2021.

In order to reach these objectives multiple econometric methods have been used. Firstly, to determine if the variables are stationary the panel unit roots test proposed by Im, Pesaran and Shin (2003) will be used. Then to check for cross-sectional dependence, the therefore

proposed test by Pesaran, Schuermann and Weiner (2001) will be used. In order to check for cointegration between the variables the panel cointegration test proposed by Johansen (1988) will be performed. Lastly, Granger causality test, firstly proposed by Granger (1969), is performed in order to determine the panel causality between the variables.

Tables 1 and 2 confirm a long term cointegration between GDP and the environmental indicators. Furthermore, they also confirm a cointegration between trade openness, urbanization, and renewable energy consumption on these indicators.

Table 1: Cointegration test results

Variables		Trace statistic	Critical Value	Probability
GDP	GHG	16.72285	15.49471	0.0325*
GDP	PM2.5	17.23872	15.49471	0.0270*
GDP	SUSTAIN	25.92548	15.49471	0.0010**
SUSTAIN	URBAN	53.96426	15.49471	0.0000**
SUSTAIN	REN	33.31240	15.49471	0.0000**
SUSTAIN	OPEN	26.58159	15.49471	0.0007**
OPEN	GHG	20.86132	15.49471	0.0015**
GHG	REN	32.83096	15.49471	0.0001**
URBAN	GHG	81.07176	15.49471	0.0000**
PM2.5	REN	38.09140	15.49471	0.0000**
PM2.5	URBAN	80.39978	15.49471	0.0000**
PM2.5	OPEN	51.89300	15.49471	0.0000**

*rejected at 5% level

** rejected at 1% level

Table 2: Granger Causality results

	GDP	GHG	OPEN	PM2.5	REN	SUSTAIN	URBAN
GDP		0.1504	0.0241*	0.0667	0.0001*	0.0649	0.0240*
GHG	0.7056		0.9755	0.0190*	0.0084*	0.8740	0.8952
OPEN	0.0010*	0.0901		0.3578	0.3253	0.2653	0.4016
PM2.5	0.5443	0.0009*	0.0372*		2.E-06*	0.3256	0.3220
REN	0.2048	5.E-05*	0.0086*	0.4748		0.4214	0.3292
SUSTAIN	2.E-07*	0.0969	0.0012*	0.5347	0.0668		0.0716
URBAN	0.3387	0.6064	0.3499	0.3858	0.6472	0.0994	

*significant at a 5% level

Keywords

Economic development, Environmental Sustainability, Europe

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