Fusarium head blight case in the context of agroecology and sustainable intensification in Europe

Myriam Deshaies *[1], Alejandro Gimeno*[2], Eric Rahn*[3] and Edward C. Rojas Tayo*[4]

* shared first authors contributed equally in this report

[1] Auranta, NovaUCD, and UCD School of Biology and Environmental Science and UCD Earth Institute, University College Dublin, Ireland

[2] Department of Plant Protection, Research Group Ecology of Noxious and Beneficial Organisms, Agroscope, Zurich, Switzerland

[3] Department of Environmental Systems Science, ETH Zurich, Switzerland

[4] Department of Plant and Environmental Sciences, University of Copenhagen, Denmark

Introduction

There is consensus that the required global increase in food demand should be reached through sustainable intensification (SI) rather than conventional intensification (CI) (Tilman et al., 2002). Nevertheless, various definitions of SI exist and there is considerable debate regarding the means to reach this goal (Tittonell, 2014; Cook et al., 2015). A common ground is that any increase in production should not come at the cost to the environment (Garnett et al., 2013). Here we follow the definition of SI given by Pretty and Bharucha (2014) as: «a process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land». European agriculture involves mainly highly intensive systems and little room for yield improvement. It is associated with environmental impacts and a decrease of agricultural land area (Buckwell et al., 2014). It is suggested that the role of European SI is to exemplify how high intensive agriculture can be combined with much higher standards of environmental performance (Buckwell et al., 2014).

Agricultural ecosystems are modified natural ecosystems, where inputs, processes and outputs are altered by agriculture to benefit human interests. Ecosystems are functional entities characterized by energy flows, nutrient cycling and population regulation (Wezel et al., 2014). Agroecology studies agricultural systems from a holistic perspective. It provides a global vision of agricultural systems rather than just a set of farming techniques, its purpose is to provide new diagnostic methodologies that allow improving agricultural systems (Altieri, 1989). Agroecology should define the ecological principles necessary to develop sustainable production systems (Gliessman, 2011). The implementation of agroecology aims to exploit or restore the natural interactions that sustain ecosystems but are disturbed during farming interventions. Its implementation in European agriculture is recommended as one approach to increase sustainability in the already highly-productive systems (FAO, 2015).

One of the main natural processes affected by agricultural practices is the balance between pathogenic and beneficial organisms. Besides the millions of losses caused by pathogens in global agriculture (between 20–40% of world production) (Savary et al., 2012), the consequent control measures (mostly based on pesticides) also generate undesired effects such as overruns, contamination, toxicity-related problems and pathogen resistance issues (MEA, 2005).

In the following section, these concepts will be discussed in the context of European wheat production. We will use the example of Fusarium head blight (FHB) to illustrate alternative control options with an agroecological approach.

The wheat-fusarium head blight problem

Wheat is the most cultivated crop in the world. It is particularly suited for temperate conditions (Curtis et al., 2002). According to the EU Cereal Farms Report 2013, cereal production occupies one-third of the EU agricultural area and one-quarter of crop production. Fungal diseases represent the main constraints for wheat production in Europe, causing high dependence on pesticides and fungicides use (Karabelas et al., 2009). This has raised concerns among governments and consumers. In fact, in 2009 the European Commission (EC) through the directive 129/EC/2009 compels its countries to move towards a sustainable use of pesticides and encourage use of alternative control measures. In contrast to one-dimensional combat strategies, SI must consider combined efforts stemming from new innovations from science and technology and already available knowledge.

FHB can be caused by a complex of several fungal species belonging mainly to *Fusarium* spp. (Osborne & Stein, 2007). It can cause losses in yield up to 50% in some areas like Canada or the US, but most importantly it significantly reduces the quality of the grain. The fungus produces mycotoxins (vomitoxin) such as deoxynivalenol (DON) that are harmful for humans and livestock (see EC, 2006). Currently, conventional breeding programs have not yet achieved highly resistant cultivars. Therefore, integrated management involves mostly cultural practices and the use of fungicides, which in some cases are not completely efficient (Gilbert & Haber, 2013). Biological control is emerging as a viable alternative to replace the use of fungicides. Extensive research argues that biological control with microorganisms that naturally antagonize pathogens could reduce the environmental side effects caused by excessive pesticides formulations (Jensen et al., 2016).

Biocontrol of FHB

A lot of research is invested for developing biological control agents (BCAs) and their application in the field, due to the increasing interest in environmental friendly solutions. Microorganisms that were isolated from healthy wheat anthers exhibited a significant effect against FHB in the greenhouse and the field by reducing the disease severity by 95% and 56% compared to the untreated control, respectively (Schisler et al., 2002). This approach is also discussed by Jensen et al., (2016) who stated that isolation of BCAs from appropriate plant parts under pertinent environmental conditions increases the likelihood of identifying effective BCAs. Xue et al., (2014) were able to demonstrate that their near-commercial formulation of *Clonostachys rosea* strain ACM941, a fungus infecting plants without being pathogenic, reduced FHB and mycotoxin contamination under field conditions with the same efficacy as commercial fungicide. Also, they showed an enhanced effect on moderately resistant cultivars. Finally, Palazzini et al., (2015) studied the impact of two bacterial strains, *Bacillus subtilis* and *Brevibacillus sp*., on FHB infection. They were applied at the anthesis stage on infected wheat during field trials. The biocontrol treatment reduced FHB severity by 62–76% and 42–58% for 2010 and 2011 trials, respectively. Moreover, treated heads did not contain any DON (mycotoxin), meaning that the bacteria completely inhibited the mycotoxin production. Regarding these successful studies, the biocontrol of FHB and possibly of other cereal diseases could become a reality.

Benefits of using biocontrols

This new type of disease management would enable to reduce or replace the use of pesticides (fungicides in this case study), enabling to shift towards sustainable intensification. Additionally, it increases food safety through reducing toxic contamination. This added value benefits the farmer and the whole food supply chain by increasing the grain quality and safety regarding the toxins. Possible synergies between plants and beneficial organisms may also contribute to further yield increase, contributing to a sustainable intensification of wheat production. Also, some biocontrols can be certified organic and, therefore, be used in organic farming, facilitating the development of a sustainable agriculture. Biocontrols are based on mechanisms already present in nature that require an understanding of the ecosystem. The use of ecosystem services is an essential part of agroecology.

Challenges in the use of biocontrols

There are uncertainties and risks associated with the use of biocontrols, as the understanding of the modes of action of biocontrols is often not elucidated yet. They might modify surrounding microorganism communities by having a microbicidal activity, and be detrimental for the environment. They might, as well have an impact on plant metabolism, which could result in a change of food composition. Their modes of action remain partly unknown and might have an impact on molecular mechanisms involved in plant development. Some of these products might specifically target one disease, resulting in the necessity for farmers to multiply the treatments with different products. Multiplying those treatments to protect plants from all sorts of pathogens would require higher financial inputs.

Conclusion

Biological control agents are a promising alternative to control FHB since they fit within the concept of agroecology and could represent a way towards sustainable intensification of wheat systems by sustaining yields while reducing the use of fungicides. However, aspects such as mode of action, molecular mechanisms involved, as well as optimal application conditions remain understudied. This knowledge is necessary to develop efficient and safer control alternatives.

Likewise, understanding how BCA interact with all the pieces of the system and how they can complement common control methods and practices is a key component in their integration to productive systems. Research, reflecting the complexity that sustainable intensification faces in already highly standardized and efficient cropping systems in temperate regions, is needed in order to modify the way FHB in controlled.

References

Altieri, M. (1989). Agroecology: a new research and development paradigm for world agriculture. *Agriculture, Ecosystems and Environment,* 27: 37–46.

Buckwell, et al. (2014). Sustainable intensification of European agriculture. A review sponsored by the *RISE Foundation*. Available at: http://www.risefoundation.eu/images/files/2014/2014_%20SI_RISE_FULL_EN.pdf

Cook, S., Silici, L., Adolph, B., Walker, S. (2015). Sustainable intensification revisited. *IIED Issue Paper*. IIED, London.

Curtis, B.C., Rajaram, S., and Macpherson, H.G. (2002). Bread wheat improvement and production. *Plant Production and Protection Series*, No. 30, FAO.

European Commission (EC) (2006). Commission Regulation. Setting maximum levels for certain contaminants in foodstuffs. European Commission, Brussels.

FAO (2015). Agroecology for Food Security and Nutrition Proceedings of the FAO International Symposium 18-19 September 2014, Rome. Introduction: Agroecology: a global movement for food security and sovereignty. By: Stephen R. Gliessman, Professor Emeritus of Agroecology: 1–15.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, 478(7369): 337–342.

IFPRI (2016). Global Nutrition Report. Available at: http://globalnutritionreport.org/the-report/

Garnett et al., (2013). Sustainable intensification in agriculture: premises and policies. *Science*, 341: 3334.

Gilbert J., Haber, S. (2013). Overview of some recent research developments in fusarium head blight of wheat. *Canadian Journal of Plant Pathology*, 35(2): 149–174.

Gliessman, S. (2011). Agroecology Ecological processes in sustainable agriculture. Introduction to Agroecology. *Lewis Publishers*: 3–15.

Jensen, D.F., Karlsson, M., Sarrocco, S., Vanacci, G. (2016). Biological control using microorganisms as an alternative to disease resistance. In: *Plant pathogen resistance biotechnology* Collinge, D.B. 341–364. Hoboken, New Jersey: *John Wiley & Sons, Inc*.

Karabelas, A., Plakas, K., Solomou, E., Drossou, V., Sarigiannis, D. (2009). Impact of European legislation on marketed pesticides – a view from the standpoint of health impact assessment studies. *Environ Int*, 35: 1096–1107.

MEA (Millennium Ecosystem Assessment) (2005). Ecosystems and human well-being: Synthesis. Island Press, Washington, DC.

Osborne L. E., Stein J. M. (2007). Epidemiology of Fusarium head blight of small-grain cereals. *International Journal of Food Microbiology,* 119: 103–108.

Palazzini, J. M., Alberione, E., Torres, A., Donat, C., Köhl, J., Chulze, S. (2016). Biological control of *Fusarium graminearum sensu stricto*, causal agent of Fusarium head blight of wheat, using formulated antagonists under field conditions in Argentina. *Biological Control,* 94: 56–61.

Pretty J., Bharucha, Z. (2014). Sustainable intensification in agricultural systems. *Ann. Bot,* 114: 1571–1596.

Savary, S. Ficke, A., Aubertot, J., Hollier, C. (2012). Crop losses due to diseases and their implications for global food production losses and food security. *Food Security,* 4(4): 519–537.

Schisler, D. A., Khan, N. I., and Boehm, M. J. (2002). Biological control of Fusarium head blight of wheat and deoxynivalenol levels in grain via use of microbial antagonists. In: Mycotoxins and Food Safety, DeVries, J.W., Trucksess, M.W., Jackson, L.S. (eds.), Boston, MA: *Springer*: 53–69.

Tilman, D., Cassman, K., Matson, P., Naylor, R., Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature,* 418: 671–677.

Tittonell, P. (2014). Ecological intensification of agriculture – sustainable by nature. *Current Opinion in Environmental Sustainabilit*y, 8: 53–61.

Wezel, A. Casagrande, M., Celette, F., Vian, J. Ferrer, A. Peigne, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development,* 34(1): 1–20.

Xue, A. G., Chen, Y., Voldeng, H. D., Fedak, G., Savard, M.E., Längle, T., Zhang, J., Harman, G. E. (2014). Concentration and cultivar effects on efficacy of CLO-1 biofungicide in controlling Fusarium head blight of wheat. *Biological Control,* 73: 2–7.