From research to practice: Multi-species and species-rich mixtures for sustainable agriculture

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Abstract

The aims of this paper are fourfold: (i) to review the scientific evidence of mixtures' contributions to sustainable grassland systems, (ii) to derive guidelines on how to compose seed mixtures, (iii) to introduce a system of elite mixtures, the Swiss Standard Mixtures (SSM), as an exemplary case for the application of mixtures in farming practice, and (iv) to discuss the relevant factors for the success of the SSM system. For all these topics, there are fundamental differences between multi-species mixtures used for intensively managed, nutrient-rich grasslands and designed to efficiently produce high yields of high-quality forage on the one hand, and species-rich mixtures used for extensively managed, nutrient-poor grasslands that are designed to promote biodiversity at the levels of communities, species, and genotypes on the other hand. The advantages of mixtures are manifold, vast and robust, and thus they are an important pillar of sustainable grassland systems. The extent and the robustness of the advantages make mixtures a reliable tool for farming practice. The recipes of the SSM follow scientifically based guidelines, are developed in multi-site experiments and tested in on-farm trials. The system of SSM offers appropriate mixtures for a wide range of durations (one year to many years), production purposes (grazing and/or cutting; intensive or extensive; green forage, hay, silage) and growing conditions (wet to dry; favourable to harsh). The system has now been successfully applied for 70 years and has been continuously adapted and improved during these decades. The most important factor for this success is the tight collaboration among all stakeholders from research, extension, teaching, and seed industry under the umbrella of the Swiss Grassland Society (AGFF). This collaboration resulted in the AGFF quality label, which distinguishes high-quality seed mixtures.

Keywords: case study, composition guidelines, mixture benefits, on-farm trials, quality label, scientific experiments

Background

Aims of multi-species and species-rich mixtures differ along with management intensity

In a world of resource scarcity, climate change and loss of biodiversity, the challenges for grassland-based forage production are demanding. Sustainable agriculture, nature-based solutions, and agroecology all aim at efficient use of resources through exploiting synergies, functional diversity, input reduction, input supplementation, promotion of biodiversity as well as soil and animal health (e.g. High Level Panel of Experts, 2019). Intensively managed, nutrient-rich grasslands containing several species and extensively managed, nutrient-poor but species-rich grasslands deliver different sets of ecosystem services (Klaus *et al.*, 2024; Richter *et al.*, 2024) and, thus, contribute differently to multifunctionality of grasslands. In this paper we aim to summarise the vast body of evidence of the mixtures' contributions to sustainable grassland systems. Based on this, a further aim is to offer guiding principles for the design of (i) multi-species mixtures for intensive management with the primary aim of efficiently producing high yields of qualitatively excellent forage and (ii) species-rich mixtures for extensively managed, nutrient-poor grasslands with the primary aim of promoting biodiversity. Finally, we introduce the Swiss System of Standard Mixtures as an exemplary case, demonstrating how these principles are applied and how mixtures have been successfully implemented for 70 years.

Multi-species mixtures for forage production

Benefits of multi-species mixtures are manifold

Multi-species grassland communities, especially those containing legumes, contribute in numerous ways to the sustainability principles mentioned above. Through positive inter-species interactions, mixtures achieve better yields than pure stands grown at the same level of resource input (Kirwan *et al.*, 2009; Finn *et al.*, 2013;). The inclusion of legumes, with their ability to symbiotically fix di-nitrogen from the atmosphere, can be a substitute for mineral nitrogen (N) fertiliser (Nyfeler *et al.*, 2011; Oberson *et al.*, 2013; Suter *et al.*, 2015) with lower risks of nitrate leaching (Nyfeler *et al.*, 2024). Although mixture yields are reduced by drought events, mixtures still achieve strong positive effects under drought stress (Hofer *et al.*, 2016; Finn *et al.*, 2018; Grange *et al.*, 2024) as well as enhance yield stability (Haughey *et al.*, 2018; Schaub *et al.*, 2020; Suter *et al.*, 2021). Moreover, mixture effects on yield have been shown to be greater at warmer than at cooler sites (O'Malley *et al.*, under revision). Thus, mixtures should be considered a crucial element of climate change adaptation. The above-mentioned positive effects are remarkably strong not only in the first year following grassland establishment (Nyfeler *et al.*, 2009; Finn *et al.*, 2013) and can be used for short-term leys as well as for permanent grasslands. They proved consistent for both cutting and grazing systems (Grace *et al.*, 2018; Roca-Fernandez *et al.*, 2016). Multi-species mixtures compared to pure stands can strongly suppress weeds (Suter *et al.*, 2017; Connolly *et al.*, 2018) and thus are an important tool for integrated weed management (Schaffner *et al.*, 2022; Sebastià *et al.*, 2025). Multi-species grass-legume mixtures improve the energy to protein ratio of forage (da Silva *et al.*, 2014) and increase milk yields when compared with the same concentrate feeding with pure ryegrass (Ineichen *et al.*, 2019). Grass-legume interactions usually form the main pillar of the mixture effects, but other interactions involving herb species (non-leguminous dicots), can contribute to yield and grassland multifunctionality (Cong *et al.*, 2018; Grange *et al.*, 2021, 2024; O'Malley *et al.*, submitted). The use of herb and legume species containing secondary plant metabolites such as condensed tannins has the potential to reduce gastro-intestinal parasite load and nitrogen losses to the environment (Malisch *et al.*, 2017; Mueller-Harvey *et al.*, 2019). Multi-species mixtures as leys in crop rotation benefit soil structure (de Haas *et al.*, 2019) and soil organic matter content (Guillaume *et al.*, 2022) leading to beneficial legacy effects on the follow-on crop (Fox *et al.*, 2020a,b; reviewed in Malisch *et al.*, 2024). Leys of two years or longer duration help to avoid crop rotation diseases (Austen *et al.*, 2022) and, thus, allow reduced plant protection interventions.

Benefits of multi-species mixtures are huge and robust

The large extent and the strong robustness of productivity benefits delivered by simple grass-legume mixtures with only four species (two legumes and two grasses) are best demonstrated by the continental-scale Agrodiversity Experiment summarised in Finn *et al.* (2013). The 31 experimental sites all had the same experimental design, resulting in a total number of 930 plots, and covered a climatic range from dry mediterranean (Spain, Sardinia) to arctic (Northern Norway, Iceland), and from Atlantic (Ireland) to continental (Poland). The pedoclimatic gradient resulted in a range of yield potential from 3 to 18 Mg/ha per year, measured as the average yield of all plots per site. Importantly, the experimental design did not only include ‘ideal’ mixtures, i.e. mixtures with an equilibrated relative abundance of the four species, but on purpose also mixtures strongly dominated by one species with 70% at sowing, and 10% of each of the other three. For results across all sites and mixture compositions, yield of the sown species of the mixture plots exceeded that of the monoculture average (overyielding) in 99.7%, and that of the best monoculture (transgressive overyielding) in 77%. The robustness of these benefits was also evident at the Swiss site of the Agrodiversity Experiment, where mixture yield significantly outperformed the best pure stand within a range of legume proportions from about 30% to 85%, and mixture yield was at least as high as the best monoculture in the range of roughly 5 to 95% of legumes (Nyfeler *et al.*, 2019). Since then, it has been repeatedly demonstrated that mixture effects can be evident even at low proportions of a species (Connolly *et al.*, 2013, 2018; Helgadóttir *et al.*, 2018; Vishwakarma *et al.*, 2023). At the Swiss site, the yield advantage of well equilibrated mixtures was so great that mixtures receiving only 50 kg N/ha per year achieved similar yields as pure grass stands with very high N application rates of 450 kg N/ha per year. The robustness of yield benefits across sites and a wide range of legume proportions has recently been confirmed with six-species mixtures by a world-wide experimental network of 26 sites within temperate zones (O’Malley *et al.*, submitted). To recommend the use of multi-species mixtures in farming practice, this robustness is of crucial importance. In nearly all situations the farmer will get a better result with mixtures than with pure stands, even if the maximal benefit of the mixture is not realised.

In conclusion, due to the great diversity, the magnitude and robustness of the mixture benefits, the question is not ‘should we use mixtures?’, but ‘which mixtures should we use?’ and ‘how can we transfer mixtures to practice?’.

Basic processes drive the design of multi-species mixtures

The three main processes leading to net diversity effects are the selection effect (Loreau and Hector, 2001), the complementarity effect (Loreau and Hector, 2001), and the insurance effect (Tilman *et al.*, 2014; Loreau *et al.*, 2021). The selection effect explains positive effects of species richness on biomass production by increased dominance of the most productive species when grown in mixture (Aarssen, 1997; Grime, 1998). The complementarity effect explains positive effects of species richness by better exploitation of limited growth resources through niche complementarity of the species (Hooper *et al.*, 2005; Tilman *et al.*, 2001). The insurance effect refers to multiple biological processes that result in the stabilisation of ecosystem functioning by species richness in a variable environment (Tilman *et al.*, 2014; Loreau *et al.*, 2021).

Declining rates of the increase of the net diversity effect with increasing species richness are expected from theory (Tilman *et al.*, 1997), and were evident from experiments examining species-rich, nutrient-poor grasslands (Hector *et al.*, 1999; Isbell *et al.*, 2017; Weisser *et al.*, 2017). The declining rates of benefits with increasing species richness imply a saturation of ecosystem function, and it is evident that saturation occurs sooner in productive, nutrient-rich conditions than in nutrient-poor grasslands (reviewed in Lüscher *et al.*, 2022). Mixtures with more than two species (i.e., compared to the still widely used *Lolium perenne* L.–*Trifolium repens* L. mixture) nevertheless have benefits with respect to productivity and multifunctionality (Grange *et al.*, 2024; O’Malley *et al.*, submitted), and provide insurance under variable environmental conditions over time and space (Finn *et al.*, 2013; Lüscher *et al.*, 2022). Indeed, when functions beyond yield and forage quality are considered, more species are likely to be needed to simultaneously sustain multiple ecosystem functions (Isbell *et al.*, 2011) due to differences in the species ability to maximise distinct functions (Grange *et al.*, 2024).

Diversity effects on yield were greatest and led more often to transgressive overyielding when either the relative abundance of the species in the mixture was equilibrated (Kirwan *et al.*, 2007, 2009; Nyfeler *et al.*, 2009; Orwin *et al.*, 2014), or when the species had a comparably high yielding potential (Roscher *et al.*, 2005). It is worth noting that transgressive overyielding is easier to achieve when the performances of the constituent species in a mixture are similar. When a species or a functional group performs markedly better than the companion species with respect to the function of interest, the optimal species proportions will shift toward this species or functional group (Vishwakarma *et al.*, 2023). For instance, targeting maximal amounts of symbiotically fixed di-nitrogen will call for high legume proportions (but not for pure legumes; Nyfeler *et al.*, 2011), while targeting high resistance to trampling will call for higher grass proportions (Suter *et al.*, these proceedings).

Based on these processes and experimental evidence, we propose that a planned design of mixtures should maximise benefits by: (i) introducing the most productive species under the given pedoclimatic conditions and production aim (to exploit the selection effect), (ii) combining species that are maximally diverse in their resource exploitation (maximising complementary effects), (iii) including species that are robust against adverse conditions in addition to the best-performing species under average conditions (exploiting the insurance effect) and (iv) combining the species in relatively even proportions within the plant community and adjusting these proportions in accordance with the main target.

Species-rich mixtures to promote biodiversity

Species composition

Semi-natural grasslands have declined by up to 95% during the 20th century and are therefore a conservation and restoration priority (Lachat *et al.*, 2010). As anthropogenically shaped ecosystems, they require continuous, low-intensity management and are therefore especially suited for ecological compensation measures in agriculture. In such species-rich, nutrient-poor and extensively managed grasslands, there is wide experimental evidence for the value of plant species richness for ecosystem functioning (Tilman *et al.*, 2001, 2014; Marquard *et al.*, 2009; Isbell *et al.*, 2015; Craven *et al.*, 2016; Weisser *et al.*, 2017). However, the effects of species composition and their relative abundance, as discussed above, were rarely examined (Finn *et al.*, 2024). In these experiments, the allocation of species to mixtures was carried out randomly from a local species pool and did not follow guidelines maximising diversity effects as suggested above. Under such conditions overyielding was very prominent but transgressive overyielding was rare (Cardinale *et al.*, 2007). For agricultural practice this is not a problem because species-rich, nutrient-poor grasslands are not cultivated for large yields of high-quality forage: the primary aim is to promote biodiversity by establishing plant communities that resemble species-rich grasslands of natural reference habitats. Consequently, guidelines for species compositions follow different recommendations than described above. These mixtures must (i) be rich of species, (ii) contain those species relevant for the reference plant community, and (iii) the species' relative abundance should resemble that of the reference community. Species with a low or even a very low proportion in the reference plant community are in focus as these are often the rare species. A major challenge is maintaining such rare species within the plant community in the long term, and high yields contradict this objective (Hautier *et al.*, 2009).

Genetic composition

Genetic diversity is critical for the resilience and long-term stability of plant populations, particularly under pressures from climate change, pests, and land-use shifts (Allendorf *et al.*, 2022). In grasslands, many species exhibit ecotypic variation – local adaptation to site-specific factors such as climate, soil, and management regimes (Bischoff *et al.*, 2010; Bucharova *et al.*, 2017; Durka *et al.*, 2019; Chung *et al.*, 2023). While the practice of grassland restoration has become increasingly mainstream, critical attention to the provenance — the geographic and genetic origin — of the seed material of native wild plants remains limited (Vogel, 2002; Mainz and Wieden, 2019; Wei *et al.*, 2023). The use of non-local wild plant material can result in the introgression of maladapted genotypes, loss of local adaptation, and long-term genetic homogenisation of native wild plant populations – thereby also undermining the potential of grasslands as reservoirs of genetic diversity for future breeding (Hufford and Mazer, 2003; Boller and Greene, 2010; Aavik *et al.*, 2012; Crispi and Hoiß, 2021; Krauss *et al.*, 2013). To safeguard local adaptation and ecosystem functioning, restoration should prioritise regionally sourced seed. This regional provenance approach supports genetic compatibility, ecological resilience, and the long-term success of restored grassland communities (Baasch *et al.*, 2016; Pedrini and Dixon, 2020). This is especially important in extensively managed grasslands, where unique ecotypes have developed over long periods of low-intensity use (Boch *et al.*, 2020).

Practical application: The Swiss Standard Mixtures

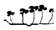
The first publication of the Swiss Standard Mixtures (SSM) for forage production dates back to 1955 (Frey, 1955). Since then, the SSM were revised every four years by adapting seed mixture recipes to new scientific results and to evolving production needs of agriculture. The system was developed because, at the time, numerous small businesses were selling their own mixtures. This resulted in a confusing myriad of poorly characterised mixtures, which made it difficult for the farmers to select the most suitable one for their aim of forage production. In addition, the basis on which these mixtures were developed and which ones performed well was unclear. Thus, the idea of the SSM was to develop a system of elite mixtures that are, on the one hand, scientifically developed and, on the other hand, follow a clear system of classification, facilitating the appropriate selection of the multi-species mixture by the farmer. A webinar introducing the core concepts and the individual steps of the development of mixture recipes is available under Lüscher *et al.* (2024).

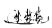
Design principles of SSM

Multi-species mixtures for production

The aim of SSM for production is to combine a relatively low number of species that are especially adapted to the intended production aim and that can fully exploit positive diversity effects. Clearly, the aim is *not* to imitate plant communities of permanent grasslands. The first principle is to choose the best-performing species under the intended production situation (duration of use, type of use, site conditions) to reflect the selection effect. Following this, the best-performing species are selected for the SSM, but also the best-performing cultivars within a species. To achieve this, it is mandatory to exclusively select cultivars of the recommended list of cultivars (Suter *et al.*, 2025a). This highlights the importance of cultivar testing for all species used for multi-species mixtures to bring the breeding progress to the farmers. In particular, the intended duration of use affects the selection of the main species (Table 1). Mixtures for only one year of utilisation (the sowing year, no overwintering), like the SSM 106 (Table 1), are dominated by Westerwold ryegrass (*Lolium multiflorum* Lam. var. *westerwoldicum* Mansh.), berseem (*Trifolium alexandrinum* L.) and Persian clover (*Trifolium resupinatum* L.). These are the species with the fastest development after sowing but with very low persistency (not winter-hardy). Mixtures for two years of utilisation (the sowing year plus one year of main utilisation) e.g. SSM 210 (Table 1) and its three derivates in the SSM system, are characterised by Italian ryegrass (*Lolium multiflorum* Lam. var. *italicum* Beck.) and short-lived red clover (*Trifolium pratense* L.). The

Table 1. Species composition, duration, intensity, drought tolerance and versatility of 10 Swiss Standard Mixtures (SSM).

Species	Growth habit	SSM (colour of label, numerical and alphabeltical code) (sowing density (kg/ha))										
		yellow	red	←	green		→	←		blue		→
		106	210	300 M	323 L	330 G	340 G	430 G	440 G	431 G	480 G	481 G
Trifolium alexandrinum L.		10	4									
Trifolium resupinatum L.		6										
Trifolium pratense L. (short-lived)			10			2	2	1	1	1		
Trifolium pratense L. (more persistent)				5	2							
Medicago sativa L.					15							
Lotus corniculatus L.												5
Trifolium repens L.						4	3	4	3	4	3	3
Lolium multiflorum Lam. var. *westerwoldicum* Mansh.		20	6									
Lolium multiflorum Lam. var. *italicum* Beck			10									
Lolium×*hybridum* Hausskn.				6								
Lolium perenne L.						7	8	10	10	3	10	3
Dactylis golmerata L.				6	6	5.5		5		5		
Festuca pratensis Hudson				10	12	12	12			8		8
Phleum pratense L.				3	3	2.5	4	3	3	3	3	2
Trisetum flavescens L.										3		
Poa pratensis L.								10	10	10	10	10
Festuca rubra L.							4	3	5	3	5	6
Cynosurus cristatus L.											5	5
Agrostis gigantea Roth											5	4
Total (kg/ha)		36	30	30	38	33	33	36	32	40	41	46
Number of species		3	4	5	5	6	6	7	6	9	7	9
Duration (years)		1	2	3	3	3	3	4+	4+	4+	4+	4+
Intensity (no. of utilisations)		2*	5	4	4	5	5	5	5	5	6	5
Drought tolerance		–	–	++	+++	+	–	+	–	+	–	–
Grazing		–	–	–	–	+	++	+	++	+	+++	+++
Green forage		+++	+++	+++	+++	+++	+++	+++	+++	++	+++	+++
Silage		+++	+++	++	++	+++	+++	+++	+++	+++	+++	+++
Hay		+++	+++	+	+	+++	+++	+++	+++	+++	+++	+++

, upright growing legume; , stoloniferous legume; , bunchgrass; , grass with extensive rhizomes; , grass with short rhizomes or pseudo-stolons; +++, excellent; ++, very good; +, good; –, bad/weak. Type of mixtures: M, dominated by long lasting red clover; ('Mattenklee'); L, dominated by lucerne, G, grass-rich.

*Sowing in the same year; number of utilisations represent an intensity comparable to 5 cuts/year of an established sward.

category of mixtures for three years is more diverse with regard to the type of utilisation (cutting, grazing) and use (green, hay, silage) as well as to growth conditions, especially drought resistance. This is reflected by different dominating species like moderately drought-tolerant long-lived red clover (*T. pratense*) in SSM 300, drought-tolerant lucerne (*Medicago sativa* L.) in SSM 323 or by different grass species and white clover (*T. repens*) that are less drought tolerant in SSM 330 (Table 1). The dominance of the high-yielding red clover or lucerne (about 2/3 of the yield) maximises the yield and the amount of symbiotically fixed di-nitrogen and makes nitrogen fertiliser unnecessary. The dominance of grasses (about 2/3 of the yield) in combination with white clover strongly increases the versatility of the mixture. The same versatility can be expected from mixtures for four and more years, e.g. SSM 431, 440 and 481 (Table 1), which are exclusively dominated by grass species and white clover, the only long-lived legume species for intensive use. The longer the mixture is to be grown, the more important it is to use species that form stolons, pseudo-stolons or rhizomes. In addition to their contribution to the persistence of the mixture, grasses and white clover are indispensable in mixtures for grazing due to their ability to form dense swards and to close gaps after trampling damage, e.g. SSM 480 or 481 (Table 1).

The second principle of designing SSM is to combine species with complementary resource exploitation to optimise complementarity effects. All SSM are grass-legume mixtures (Table 1), reflecting the exploitation of complementarity by combining grasses and legumes. Many experiments demonstrated that legume × grass interactions were the most important to generate positive diversity effects. This is mainly related to the legumes' ability to symbiotically fix di-nitrogen from the atmosphere and the grasses' strong requirement of nitrogen for growth (Nyfeler *et al.*, 2011). In addition, grasses with their shallow root system and fast growth in spring and the legumes with their taproots (except white clover) and persistent growth in summer exhibit further important traits for resource complementarity (Hoekstra *et al.*, 2015; Husse *et al.*, 2016).

The composition of all SSM for longer duration (Table 1: 3 years, 4+ years) follows the principle of succession. Species that are fast establishing after sowing but not persistent (typically *T. pratense*, *L. multiflorum* var. *italicum*, *L. multiflorum* var. *westerwoldicum*, *Lolium* x *hybridicum* Hausskn.) or persist only under the most favourable growth conditions and optimal management (*L. perenne*) are combined with species that are slower to establish but are more persistent (typically *T. repens*, *Dactylis glomerata* L. or *Poa pratensis* L.). This is exploiting complementarity in terms of the temporal niche across years, but also has an insurance effect, as distinct species can take over more quickly if growth conditions are adverse. The temporal succession over the years from the fast-establishing red clover to the more persistent cocksfoot was well demonstrated in the Agrodiversity Experiment (Finn *et al.*, 2013). Generally, the longer the duration and the less favourable the growing conditions, the higher the proportion of insurance species and the lower the relative abundance of *Lolium* spp. in the seed mixture (compare durations of 3 and 4+ in Table 1, e.g. SSM 431 and 481 for sites, where *Lolium* spp. cannot develop their full potential). The reduced relative abundance of *Lolium* spp. is important to prevent these fast-growing species from outcompeting the slow establishing species during the first two years.

Species-rich mixtures for biodiversity promotion

In Switzerland, the species composition of species-rich mixtures to promote biodiversity is based on natural reference vegetation, following the classification system TypoCH (Delarze *et al.*, 2015), which is officially recognised in Switzerland. For the SSM, four widely accepted species-rich mixtures were developed to restore three key habitat types: (i) lowland to mid-elevation hay meadows (*Arrhenatherion*; two mixtures), (ii) mountain hay meadows (*Polygono-Trisetion*), (iii) sub-atlantic semi-dry calcareous grasslands (*Mesobromion*). These habitat types correspond to (i) R222, (ii) R233 and (iii) R1A32 in the European Nature Information System (EUNIS) habitat classification (European Environment Agency, 2021). These mixtures are:

SSM 'Salvia': A lowland meadow for dry to mesic sites, based on the *Arrhenatherion* habitat, towards the dryer habitat *Salvio-Arrhenatherion*, containing 38 plant species.

SSM 'Humida': A mixture for moister (but not shaded) sites, also based on the *Arrhenatherion* habitat, leaning toward the moister *Trifolio-Alopecuretum*, containing 35 plant species with 10 of them not being part of the dryer *Salvio* association.

SSM 'Montagna': A mountain meadow (up to 1500 m a.s.l.), corresponding to *Polygono-Trisetion*, containing 31 species.

SSM 'Broma': A semi-dry grassland mixture for nutrient-poor soils, reflecting *Mesobromion* grasslands. This mixture contains seeds of 47 plant species, 14 of them not represented in any of the other three mixtures.

For detailed species composition see Suter and Frick (2025).

All components of these mixtures are derived from Swiss source populations. However, Switzerland's pronounced geographic and climatic heterogeneity – reflected in its distinct biogeographic regions – demands careful attention to provenance (BAFU, 2022). To safeguard local adaptation and genetic diversity, the use of seed within defined seed transfer zones aligned with these biogeographic regions has become a widely accepted approach (Cevallos *et al.*, 2020; Durka *et al.*, 2025; Höfner *et al.*, 2022). Currently, most native wild species used in species-rich SSM originate from the Swiss Plateau. Consequently, the existing mixtures are particularly well suited – both genetically and climatically – for restoration projects in this region. This focus also follows an ecological strategy, as the Swiss Plateau is facing the highest biodiversity deficits nationwide (Meier *et al.*, 2021). Seed producers continuously expanded the collection and propagation of wild plant populations from additional biogeographic regions. Thus, they are able to prepare more specific customised mixtures upon request, using available regionally appropriate seed sources.

Key factors for the success of the Swiss Standard Mixtures

The success of the SSM is outstanding in two ways: first, they have been an important tool of Swiss grassland agriculture for seven decades and second, about 80% of the seeds for Swiss grasslands are traded as SSM. This raises the question of the key factors behind this success.

Success-factor 1: Mixtures adapted to a broad range of needs, but easy to recognise

With its 46 multi-species and species-rich mixtures, the system of SSM is diverse and offers an appropriate solution for all relevant production situations. The mixture choice is derived from the combinations of (i) duration of utilisation (one to many years), (ii) growth conditions (wet to dry, mild to harsh) and (iii) type of utilisation (pasture and/or cutting, intensive management for high-quality forage to extensive management to promote biodiversity). The systematic classification of the mixtures according to these three axes and the use of a three-digit code makes it relatively easy to recognise the appropriate mixture to be used. The first digit of the code designates the main group 'duration of utilisation', and this main criterion is also made visible by a distinct colour of the label on the seed bag (Table 1). For mixtures designed for longer duration (3 years and 4+ years) an additional alphabetic character indicates the main legume species and the abundance of legumes in the sward (Table 1). Mixtures with an 'M' ('Mattenklee-mixture') are dominated by the more persistent Swiss 'Mattenklee' (*T. pratense*) and those with an 'L' ('Lucerne-mixture') by lucerne (*M. sativa*). Therefore, they cannot be grazed and hay making is difficult. In contrast, mixtures with a 'G' ('Grass-white-clover-mixture') are grass-rich and their main legume is white clover. They can either be grazed or cut and used as green forage, hay or silage (Table 1).

Success-factors 2 and 3: Scientific development and on-farm testing
Although the principles of designing multi-species mixtures are established (see above), mixture recipes must be developed, tested and optimised in a framework of scientifically designed multi-site small plot experiments. In addition to long-term observations on yield and forage quality, the development of the botanical composition is key. A major challenge is to find the relative abundance of each species in the seed mixture that later results in their desired relative abundances in the sward. However, such small plot experiments provide rather limited information about how robust a seed mixture of a given recipe would perform under variable management practices. Therefore, the most promising recipes from the small plot experiments are subjected to upscaled on-farm, strip-plot trials under the farms' own utilisation practices. The different management techniques, and even occasional mistakes regarding mowing, grazing or fertilising, exert an important stress and contribute to testing the robustness and practical feasibility of the recipes. Only after passing these practical tests is a candidate recipe recommended as an SSM. The agronomic performance of these SSM is impressive: they delivered higher yields and more persistent legume proportions than the mixtures of the Agrodiversity Experiment (Suter *et al.*, 2010).

Success-factors 4 and 5: Collaboration and quality label
An exemplary national collaboration among research, development, extension, teaching, and the seed industry (Swiss-Seed) under the umbrella of the Swiss Grassland Society (AGFF) is certainly an important success factor for wide acceptance of the system of standard mixtures in Switzerland. The Swiss Grassland Society supports the on-farm testing programme. For this, mainly farms belonging to a regional extension centre or an agricultural school are chosen. Like this, the strip trials can also be used for demonstration purposes. The Swiss Grassland Society label emphasises the quality-based approach by guaranteeing that (i) the seed mixture follows the recipe as published for the respective SSM (Suter and Frick, 2025), which is based on scientific development and on-farm testing, (ii) the use of recommended cultivars (Suter *et al.*, 2025a), and (iii) VESKOF® quality seeds (Swiss-Seed, 2018), which have a higher purity and better germination ability than legally required. Regular examination of commercial seed samples ensures the label's acceptance.

For species-rich mixtures aimed at promoting biodiversity the joint effort of the Swiss Grassland Society and InfoFlora have led to the establishment of RegioFlora, a coordination and advisory body dedicated to the conservation and promotion of native plant genetic resources in agriculture. For these mixtures the Swiss Grassland Society quality label not only guarantees the published seed mixture composition (Suter and Frick, 2025), but also places particular emphasis on species authenticity, ensured through field controls carried out by RegioFlora and the use of appropriate regional provenances.

Success-factor 6: Continuous adaptation and improvement
When the first SSM appeared in 1955, forage production was not as intensive as it is today. The steadily increasing milk yield of dairy cows required ever better feed quality. The progress in mechanisation

of forage harvesting and conservation enabled the intensification of production. This development is reflected by the decrease in the share of mixtures for less-intensive use from 53% in 1955 to 23% in 2025, a corresponding increase in the share of mixtures for intensive use from 33 to 70%, and a threefold increase in the number of grass-rich mixtures with white clover (Frey, 1955; Suter and Frick, 2025). The anticipation of future changes in growth conditions, e.g. more frequent dry periods, led to the development of more drought tolerant mixtures for grazing (SSM 362 and 462). To support the control of gastro-intestinal parasites in grazing animals with tannin-rich fodder, SSM 326 with sainfoin (*Onobrychis viciifolia* Scop.) was developed. While this development mainly supported the progress in agricultural production, it contributed little to offset the loss of biodiversity resulting from the fast shift from comparably extensive towards intensive farming. Thus, in 1988 the first mixtures for biodiversity promotion programmes containing Swiss wild plants were introduced and continuously developed ever since (see above).

Conclusions

Experimental evidence for the wide variety, the magnitude, and the impressive robustness of positive effects of mixtures as compared to pure stands is overwhelming. The set of ecosystem services delivered by grasslands differ widely depending on management intensity. Consequently, the guidelines on how to compose multi-species mixtures for intensive and efficient production of high-quality forage differ fundamentally from those for species-rich and extensively managed mixtures for the promotion of biodiversity. Multi-species mixtures for production do not aim to mimic permanent grassland communities. They should maximise benefits by achieving relatively even communities of a comparably small number of high-yielding plant species that complement each other ideally in their resource exploitation and robustness against adverse conditions. Species-rich mixtures for the promotion of biodiversity at the levels of grassland communities, plant species, and genotypes should mimic species composition and abundance of typical semi-natural grassland communities and pay special attention to the genetic integrity of propagated wild plant populations. The exemplary case of the Swiss Standard Mixtures (SSM) system demonstrates how these principles have been successfully integrated into farming practice for 70 years at the national level. This success is based on the scientific development of a broad range of mixture recipes combined with on-farm testing and close collaboration of all stakeholders, which allows continuous improvement of the SSM system and cumulates in the quality label for high-quality seed mixtures awarded by the Swiss Grassland Society (AGFF).

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