agriculture

MDPI

Editorial

Intercropping Systems for Sustainable Agriculture

Martin Weih [1,*], M. Inés Mínguez [2] and Stefano Tavoletti [3]

1 Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), 75007 Uppsala, Sweden
2 Departamento de Producción Agraria-CEIGRAM, Universidad Politécnica de Madrid (UPM), 28040 Madrid, Spain; ines.minguez@upm.es
3 Department of Agricultural, Food and Environmental Sciences, Università Politecnica delle Marche, 60131 Ancona, Italy; s.tavoletti@staff.univpm.it
* Correspondence: martin.weih@slu.se; Tel.: +46-18-672543

check for updates

Citation: Weih, M.; Mínguez, M.I.; Tavoletti, S. Intercropping Systems for Sustainable Agriculture. *Agriculture* **2022**, *12*, 291. https://doi.org/10.3390/agriculture12020291

Received: 9 February 2022
Accepted: 14 February 2022
Published: 17 February 2022

Increasing sustainability in agriculture is an imperative target for whole food and feed production and transformation chains. For this purpose, considerable attention has been paid to the contribution of intercropping systems to increasing and exploiting biodiversity, reducing the use of fertilizers and agrichemicals, adaptation to and mitigation of climate change, and supporting low-input and organic agricultural systems. However, farmers and agricultural advisors need scientific and technical support to implement intercropping into agricultural systems and value chains that still are mainly based on sole crops. Moreover, pedo-climatic differences, agricultural and food systems, and consumer habits vary between different regions, calling for regional or even local solutions.

This Special Issue contains five papers originating from five different continents (Europe, North and South America, Asia, Australia), and covering (i) the grain yield stability of various barley–pea and wheat–faba bean mixtures grown in seven experimental field trials (locations) across Europe [1]; (ii) the evaluation of three cover crop treatments on cover crop biomass, soil cover, plant density, and soybean yield in the northwestern Corn Belt in the USA [2]; (iii) the performance of signal grass (*Urochloa decumbens*) pastures intercropped with a legume (calopo, *Calopogonium mucunoides*) in Brazil [3]; (iv) the impact of intercropping maize with potato on yield, water use, energy output, and net economic return on the Loess Plateau in China [4]; and (v) a review of the main existing metrics used in the scientific literature to assess intercropping systems at large scale and in an Australian perspective [5].

The intercropping of two or more crop species on the same piece of land at a given time has frequently been hypothesized to enhance crop yield stability. To test this hypothesis, Weih et al. [1] assessed the grain yield stability in intercropping with various barley–pea and wheat–faba bean mixtures grown across Europe in experimental trials in seven locations, and for two years with contrasting weather (2017 and 2018). The methodology in place to test the hypothesis included three yield stability measures based on the expected yield variability of the mixture components grown as sole crops, and the corresponding observed yield variability of the same components grown in 50:50 mixtures in a replacement design. Stability indices were calculated as ratios between the expected and observed variabilities. The work highlighted two important issues among others: first that mean grain yields tended to be greater in intercrops than in sole crops, and second that although there was no evidence for a general yield-stabilizing effect of intercrops, yield stability significantly increased with increasing mean yields when assessed across differentially productive locations. These results are relevant for the designing of intercropping systems to increase yield stability and the resilience of cropping systems in higher yielding conditions. The yield-stabilizing effects of intercrops can probably be further enhanced by designing locally adapted crop/cultivar combinations. Functional asynchrony was also discussed as an important property of intercrop components that could further justify why a given combination of crops supports increased stability when grown in intercrops. Indications for functional asynchrony in pea vs. barley, but not wheat vs. faba bean were found, although no clear relationship with stability was deducted.

Intercropping also includes the aspect of growing a primary crop with a cover crop that provides benefits to the primary crop and/or to the overall farm system in terms of enhanced sustainability. The research by Kandel et al. [2] evaluated the effectiveness of using rye and winter camelina (*Camelina sativa*) as cover crops in a rotation that involved soybean and wheat as sole primary crops to exploit the cover crop potential in soil protection, increased ecosystem services due to a more complex agricultural system and in reducing soil erosion. The study included field trials carried out in five locations for two successive years that were characterized by different environmental conditions mainly related to variable precipitation levels that affected both soybean and cover crop performance. Two soybean varieties characterized by different lengths of the crop cycle were included and tested using two sowing densities. Results highlighted that none of the studied cover crops affected soybean performance, whereas the early maturing soybean variety showed a lower yield than the late maturing one. Moreover, a better soybean performance for both varieties was obtained by narrower row spacing, and soybean row spacing did not affect biomass yield and soil coverage level of both species used as cover crops. Interestingly, clear differences were detected between the effects of the two cover crops rye and camelina. Although rye was characterized by a significantly higher soil coverage and biomass than camelina, wheat performance after rye was significantly lower than after camelina. Authors discuss in detail the advantages and disadvantages of each of the cover crop species, together with an evaluation of the competitiveness of soybean on the two cover crops through a specifically tuned treatment combination including sowing the cover crop with soybean or after elimination of soybean plants to avoid competition for the cover crop. Overall, the authors concluded that camelina is to be preferred to rye as a cover crop, although its overall performance in terms of biomass and ability to protect soil from wind erosion must be better investigated.

For many years, agronomists have been attracted by the idea to increase sustainability in agriculture through combining a nitrogen-fixing legume crop with a crop that demands high nitrogen resources to produce high yields, i.e., the nitrogen-fixation of the legume could (partly) replace nitrogen fertilization. A specific example for this idea is the study by Chaves et al. [3], which addresses the performance of deferred signal-grass (*Urochloa decumbens*) pastures in Brazil in response to four treatments including three nitrogen fertilization treatments (zero, low and high fertilization), and intercropping with the legume calopo (*Calopogonium mucunoides*). Deferment, or deferred grazing, is a management tool to maintain pasture quality on pastoral farms and implies the postponing or delaying of grazing to increase pasture performance in terms of forage mass, chemical composition, and structural characteristics affecting animal production. The authors hypothesized that signal grass fertilization and/or intercropping with calopo should result in increased biomass as well as improved structural characteristics and chemical composition of forage during the dry season after deferment. A main result was that the intercropping of signal grass with the legume (i.e., calopo) resulted in similar forage biomass quantity and quality (in terms of crude protein content) compared to nitrogen fertilization; and they evidenced this result with various assessments including sward height, falling indices, green and stem dry masses, forage accumulation, tiller number, and quality measures like insoluble neutral detergent fiber (NDF) and crude protein (CP) contents. The authors concluded that whilst the positive effect of nitrogen fertilization on forage quantity and quality in deferred pastures is well-known, the same effect can be achieved also by intercropping with a legume, in this case, calopo, offering a novel management strategy avoiding or reducing nitrogen fertilization and thus supporting a more sustainable pasture management.

Another attractive aspect of intercropping is the potential of mixed crops to increase resilience, especially under harsh climate conditions. As an example for this aspect, Xi et al. [4] evaluated the opportunity of exploiting maize-potato intercropping (as opposed to sole cropping) to better tackle the harsh climatic conditions characterizing the Loess Plateau in China. This research showed that strip intercropping supported by the application of a plastic film fully mulched ridge-furrow system (FMRF) positively affected yield (Land Equivalent Ratio, LER index > 1), soil water storage deficit, water use, water use efficiency, water equivalent ratio, energy output. However, the results also showed poor evidence for an overall advantage of intercropping over sole cropping in terms of economic returns. Overall, the biennial field trial was conducted in a location characterized by harsh environmental conditions that strongly influence agricultural crop performance. Moreover, two very contrasting years were considered. Results highlighted important advantages of intercropping compared to sole cropping for aspects related to crop water use in locations characterized by dry conditions that strongly impact crop performance in rainfed farming systems. The best performance was obtained by using plastic films coupled with mulched ridge furrows, affecting the costs of intercropping management and consequently the net economic return.

Assessment of the pros and cons of intercrops compared to sole crops can be done using different metrics, including both purely agronomic measures such as yield performance and Land Equivalent Ratios (LER), but also economic profit returns and risk assessments. The paper by Khanal et al. [5] reviews the main existing metrics used in the scientific literature to assess intercropping systems, and also provides a comprehensive discussion on the benefits, costs and risks of adopting intercropping systems, mainly adopting an Australian broadacre perspective. Broadacre is here used to describe farms involved in the production of crops on a large scale. Currently, a variety of metrics are available to compare intercropping and sole cropping systems. Despite the method of evaluation, the underlying basis is always a comparison of the direct short-term performance of the intercrop to the monoculture. Land Equivalent Ratio (LER), other yield-based measures, commodity value measures, profit measures, risk measures and measures of indirect benefits were considered in the review. The choice of methods depends on the objective of adopting the crop mixture, and the paper discusses various examples for objectives and the appropriate methods to address them. These numerous illustrative examples are perhaps the greatest asset of this paper. In reality, several objectives might be useful to be considered jointly by agricultural stakeholders, and it might therefore be meaningful to employ several measures simultaneously in evaluating the performance of intercrops. The authors argue that the total economic value of the intercropping system, rather than only the agronomic yield, needs to be valued as far as possible, although the profitability of intercropping cannot be judged without considering the specific crops grown. Apart from yield and profit-related considerations, also other factors that could potentially affect the level of adoption (of intercrops) by the growers should be considered, including the availability of appropriate machinery (harvesting mixed crops and separating grains), growers' skills, and consequently the possible need for capacity building. Thus, the evaluation of advantages of intercropping—yield-, profit- and environment-related ones—should consider not only the potential benefits, but also the costs associated with its adoption. Finally, the authors recommend the use of the net gross margin, profit ratio and a 'certainty equivalent' measure that can take into account all specific differences in costs and benefits between intercropping and sole cropping systems, including the implications for economic risk and risk evaluation.

The five contributions to this Special Issue combine a nice collection of works showcasing how intercropping could successfully contribute to greater sustainability in agriculture, and the reported results and insights are inspiring reading for everybody interested in the challenges but also limitations of intercropping. We would especially like to thank the various anonymous reviewers for their contributions to this Special Issue. The guest editors for the present Special Issue were as follows: Prof. Stefano Tavoletti, Università Politecnica delle Marche, Ancona, Italy; Prof. Dr. M. Inés Mínguez, Technical University of Madrid, Madrid, Spain; and Prof. Martin Weih, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Funding: The compilation of this Special Issue was supported financially by the DIVERSify project, a grant from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 727284.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Weih, M.; Karley, A.J.; Newton, A.C.; Kiær, L.P.; Scherber, C.; Rubiales, D.; Adam, E.; Ajal, J.; Brandmeier, J.; Pappagallo, S.; et al. Grain Yield Stability of Cereal-Legume Intercrops Is Greater Than Sole Crops in More Productive Conditions. *Agriculture* **2021**, *11*, 255. [CrossRef]
2. Kandel, H.J.; Samarappuli, D.P.; Johnson, K.L.; Berti, M.T. Soybean Relative Maturity, Not Row Spacing, Affected Interseeded Cover Crops Biomass. *Agriculture* **2021**, *11*, 441. [CrossRef]
3. Chaves, C.S.; Ribeiro, K.G.; Pereira, O.G.; da Fonseca, D.M.; Cecon, P.R.; Gomide, C.A.d.M. Signal Grass Deferred Pastures Fertilized with Nitrogen or Intercropped with Calopo. *Agriculture* **2021**, *11*, 804. [CrossRef]
4. Xie, J.; Wang, L.; Li, L.; Anwar, S.; Luo, Z.; Zechariah, E.; Kwami Fudjoe, S. Yield, Economic Benefit, Soil Water Balance, and Water Use Efficiency of Intercropped Maize/Potato in Responses to Mulching Practices on the Semiarid Loess Plateau. *Agriculture* **2021**, *11*, 1100. [CrossRef]
5. Khanal, U.; Stott, K.J.; Armstrong, R.; Nuttall, J.G.; Henry, F.; Christy, B.P.; Mitchell, M.; Riffkin, P.A.; Wallace, A.J.; McCaskill, M.; et al. Intercropping—Evaluating the Advantages to Broadacre Systems. *Agriculture* **2021**, *11*, 453. [CrossRef]