agriculture

Editorial

Agricultural Diversification

Claudia Di Bene [1,*], Rosa Francaviglia [1], Roberta Farina [1], Jorge Álvaro-Fuentes [2] and Raúl Zornoza [3]

[1] Research Centre for Agriculture and Environment, Council for Agricultural Research and Economics (CREA), 00184 Rome, Italy; r.francaviglia@gmail.com (R.F.); roberta.farina@crea.gov.it (R.F.)
[2] Estación Experimental de Aula Dei, Spanish National Research Council (CSIC), 50059 Zaragoza, Spain; jorgeaf@eead.csic.es
[3] Sustainable Use, Management, and Reclamation of Soil and Water Research Group (GARSA), Department of Agricultural Engineering, Universidad Politécnica de Cartagena, 30203 Cartagena, Spain; raul.zornoza@upct.es
* Correspondence: claudia.dibene@crea.gov.it

Citation: Di Bene, C.; Francaviglia, R.; Farina, R.; Álvaro-Fuentes, J.; Zornoza, R. Agricultural Diversification. *Agriculture* **2022**, *12*, 369. https://doi.org/10.3390/agriculture12030369

Received: 27 February 2022
Accepted: 4 March 2022
Published: 5 March 2022

Agricultural intensification is a highly specialized agri-food system that has contributed to raising food production worldwide due to progress in agricultural machinery and technologies, the use of improved cultivars, and external inputs such as fertilizers, irrigation, and pesticides. Nevertheless, agricultural intensification and unsustainable soil management negatively influence the environment through a decrease in air and water quality, soil erosion, depletion of soil organic matter, resistance of weeds, pests, and pathogens to pesticides, and a decrease in soil quality and agrobiodiversity. It is well-known that some changes in agricultural systems are needed for their sustainability through balancing socio-economic food production aspects with environmental goals. In this context, appropriate diversification strategies and management practices are crucial for promoting the re-design of intensive agricultural systems.

Several authors agree that crop diversity can improve crop productivity and resource use efficiency by delivering multiple ecosystem services. Coupling agricultural diversification including crop rotation, cover crops, multiple cropping and/or intercropping with low-input management strategies such as, agroecology, conservation agriculture, and organic farming contributes to increasing crop productivity and cropping system resilience in the long-term.

Despite the large scientific consensus on the potential agro-ecological and socio-economic benefits of crop diversification, some financial instruments might be necessary to favour the adoption of combined agricultural diversification strategies since the economic costs in the short-term can offset the environmental and ecological benefits in the long-term. Particularly, the re-design and diversification of agricultural intensification imply specific transition costs that must be considered by farmers and advisors in the short- and medium-term. Such costs are related to acquire new technical skills and knowledge to manage the risks due to "unknown" crops and their new market, especially in the initial implementation phases.

Therefore, research and policy must play a key role in supporting more sustainable practices for agri-food production while ensuring environmental improvements.

This Special Issue covers several topics of research relative to agricultural diversification in different parts of the world and cropping systems, where novel approaches were suggested to evaluate cropping system diversification strategies in comparison with conventional practices.

This special issue has a total of 13 research articles submitted by authors from seventeen countries: Canada, Chile, China, Ecuador, France, Germany, Italy, Lithuania, Mali, New Zealand, Niger, Poland, Singapore, Spain, Sweden, United States, and Vietnam.

The first article by Tan et al. [1] addresses the problem of poor crop productivity resulting from salinity intrusion and occasional disease outbreaks occurring in mono-cropping of rice for farmers in the Mekong Delta (Vietnam). Commonly practiced alternative farming models including the rotation of rice with fishes, shrimps, and subsidiary crops, the intensive monoculture of snakehead murrel fish and blue prawns, intercropping of blue prawn in rice paddy fields, and intercropping of blue prawn in coconut irrigation channels have been evaluated in terms of soil and water quality indicators. Among such models, the rotation of rice with different shrimp species has been demonstrated to be economically successful and ecologically sustainable, showing good adaptation to saline conditions and enabling farmers to overcome white spot disease.

The second paper by Udawatta et al. [2] examined the effects of crop management practices such as cutting height, cutting time, and the influence of plant mixture diversity on feedstock yields for bioenergy production in Missouri (USA). A monoculture of switchgrass was established along with plots that contained equal combinations of switchgrass and big bluestem. Each of these combinations also contained mixtures of native forbs and legumes seeded at various grass-to-forb ratios. The effect of species mixture was not significant on yield, while the cutting height was significant, with greater yield for the 15 cm compared to the 30 cm cutting height. However, results showed that mixtures of native warm-season grasses, forbs, and legumes are suitable for biomass production and forage crops in Missouri and can provide a source of forage during extreme summer drought conditions. When managing a forage stand using native grasses with mixtures of forbs and legumes, the frequency of cutting and timing of harvests may help to adjust costs and income potential as well as optimize equipment efficiency.

The third article by Sogoba et al. [3] addressed the cereal-cowpea intercropping practiced by smallholder farmers in Mali, a common cropping system in the Sudano-Sahelian zone of West Africa. Whether intercropping with millet or sorghum, and whatever the seasonal rainfall, the best grain yield was obtained with the wilibali (short maturing duration) variety and the best biomass yield was obtained with the sangaranka variety, which is a long-maturing duration variety. The study revealed strong trade-offs between household food opportunities and animal feeding and economic gain regarding cereal-cowpea intercropping in southern Mali. The knowledge generated revealed opportunities for alleviating some of the trade-offs and achieving more promising farming decisions based on specific farm needs. Farmers selected cereal in intercropping with short maturing duration such as the wilibali variety to mainly address household food needs at specific periods corresponding to food shortages. While for those farmers prioritizing animal feeding, especially agro-pastoralists, the sangaranka variety was the best option. On the other hand, from an economic point of view, millet intercropping with cowpea was more profitable than sorghum intercropping with cowpea. Yield variability and low yields of both cereals and cowpea for all varieties combined indicated opportunities for improvement in both research and farming.

The paper by Vera-Aviles et al. [4] studied the abundance of the macro edaphic fauna and identified the beneficial families to determine the equilibrium level of the Musaceae agroecosystem in Ecuador. The mixed type of production system provides plant diversity, which favors arthropod abundance and permits lower agrochemical application without yield penalties in comparison to monocultivar systems. Within Hexapoda, the orders that presented larger populations were Collembola and Hymenoptera (based on the abundance and distribution they presented). The order Hymenoptera dominated in all of the treatments, both by its abundance and by its distribution in the studied localities, even in ecosystems with ecological imbalance. The management practices in agroecosystems can alter the community structure of pests' natural enemies, which can consequently influence their biocontrol. Since the functional composition of natural enemy communities, rather than taxonomic diversity, drive pest suppression efficiency, it is necessary to employ the functional approach to investigate the impact of management on natural enemies. Our findings showed that intraspecific diversity could be a good option to include in an IPM strategy for small and medium farmers and may help in the design of Musaceae agroecosystems to enhance the ecological regulation of pest management without putting on the farmer the constraint of management different crops.

Carton et al. [5] compared the weed suppression and yield performance between winter white lupin-triticale intercropping and lupin sole cropping throughout a set of eleven experiments during a two-year period in western France. Comparing the intercrop and the sole crop in the context of the transition to low-input crop management strategies is increasingly needed as solutions for chemical weeding are becoming scarce. In this context, results indicated that the lupin-triticale intercrop is a relevant option. Considering that a moderate lupin yield reduction can lead to a high protein yield loss, intercropping lupin with triticale does not seem to potentially perform better than sole cropping lupin regarding protein productivity on an area basis. At a broader scale, intercropping could allow an increase in lupin cropping area via increased lupin adoption by farmers due to increased weed suppression and secured total productivity. In this case, lupin intercropped with cereals could significantly contribute to the production of protein-rich grains in Europe.

Intercropping was also addressed by Munz and Reiser [6]. The agronomic optimization of intercropping systems is a challenging task given the numerous management options and the complexity of interactions between the crops and efficient methods for analyzing the influence of different management options are needed. The canopy cover of each crop in the intercropping system is a good determinant for light competition, thus influencing crop growth and weed suppression. Therefore, the study evaluated the feasibility to estimate canopy cover within an intercropping system of pea and oat based on semantic segmentation using a convolutional neural network. The network was trained with images from three datasets during early growth stages comprising canopy covers between 4% and 52%. Only the images of sole crops were used for training and then applied to images of the intercropping system. The results showed that the networks trained on a single growth stage performed best for their corresponding dataset. Combining the data from all three growth stages increased the robustness of the overall detection, but decreased the accuracy of some of the single dataset result. The accuracy of the estimated canopy cover of intercropped species was similar to sole crops and sufficient to analyze light competition.

Calvache et al. [7] examined the dynamics of water-soluble carbohydrates (WSC) use and the recovery of leaf sheaths and blades of pastures of *Bromus valdivianus* Phil. and *Lolium perenne* L. subjected to two defoliation frequencies (DFs) determined by accumulated growing degree days (AGDDs) in southern Chile. The authors also evaluated how DF influenced regrowth and accumulated herbage mass during fall. The study indicated that the leaf sheath was the principal storage organ for WSC reserves, having higher concentrations than leaf blades in fall pastures. Approximately 80% of total WSC was used during the regrowth process before WSC storage recommenced. Defoliation frequency affected WSC concentration, with longer intervals between defoliation (270 AGDDs) being preferred since the plants could recover 99% of WSC reserves and could tolerate another grazing event better. Defoliation with greater frequency (135 AGDDs) diminished the synthesis and storage of WSCs and led to slower regrowth of pasture.

The study by He et al. [8] combined statistic and economic models to evaluate the comprehensive effects of cropping systems on rice production using data collected from experimental fields. The results showed that increasing agricultural diversity through rotations, particularly potato–rice rotation (PR), significantly increased the social, economic, and ecological benefits of rice production. Yields, profits, profit margins, weighted dimensionless values of soil chemical and physical and heavy metal traits, benefits and externalities generated by PR and other rotations (e.g., fallow followed by rice (FR), and watermelon and rice rotation (WR)) were generally higher than continuous rice cropping. This suggests that agricultural diversity through rotations, particularly PR rotation, is worth implementing due to its overall benefits generated in rice production. However, due to various nutrient residues from preceding crops, fertilizer application should be rationalized to improve the resource and investment efficiency. Furthermore, the externalities (hidden ecological and social benefits/costs) generated by each of the rotation systems and the proposed ways of incenting farmers to adopt crop rotation approaches for sustainable rice production were internalized.

Dittrich et al. [9] investigated the effects of intercropping grapevine with aromatic plants using a multi-disciplinary approach. In particular, they addressed the extent to which crop diversification by intercropping impacts grapevine yield and must quality, as well as soil water and mineral nutrients (NO_3-N, NH_4-N, plant-available K and P). The experimental field was a commercial steep-slope vineyard with shallow soils characterized by a high presence of coarse rock fragments in the Mosel area of Germany. The field experiment was set up as randomized block design. Rows were either cultivated with Riesling (*Vitis vinifera* L.) as a monocrop or intercropped with *Origanum vulgare* L. or *Thymus vulgaris* L. Regarding soil moisture and nutrient levels, the topsoil (0–0.1 m) was more affected by intercropping than the subsoil (0.1–0.3 m). Gravimetric moisture was consistently lower in the intercropped topsoil. While NO_3-N was almost unaffected by crop diversification, NH_4-N, K, and P were uniformly reduced in topsoil. Significant differences in grapevine yield and quality might be dominantly attributable to climate variables, rather than to the treatments. Additionally, they also observed some insignificant yield losses due to intercropping, particularly induced by water competition. With respect to this, thyme appeared to be less competitive due to an earlier harvest date and a lower respectively shorter consumption of soil water during the crop cycle. The authors concluded that yield stabilization due to intercropping with thyme and oregano seems possible with sufficient rainfall or by irrigation.

Gecaitė et al. [10] conducted field experiments to determine yield formation regularities and plant competition effects of oat–black medick, oat–white clover, and oat–Egyptian clover relay intercropping under organic farming conditions. Oats and forage legumes were grown in mono- and intercrops. Aboveground dry matter measured at flowering, development of fruit and ripened grain, productivity indicators, oat grain yield, and nutrient content were established. The results showed that oats dominated in the intercropping systems. Oat competitive performance, which is characterized by forage legumes aboveground mass reduction compared to monocrops, was 91.4–98.9. As the oats ripened, its competitiveness tended to decline. In oat–forage legume intercropping systems, the mass of weeds was significantly lower compared to the legume monocrops. Oats and forage legumes competed for P, but N and K accumulation in biomass was not significantly affected. They concluded that, in relay intercrop, under favorable conditions, the forage legumes can easily adapt to the growth rhythm and intensity of oats and without adverse effect on their grain yield.

The challenges for food planning and policy in the regionalization of food systems, in order to shorten supply chains and develop local agriculture to feed city regions, were addressed in the article by Vicente-Vicente et al. [11]. The existing foodshed approaches enable them to assess the theoretical capacity of the food self-sufficiency of a specific region, but they struggled to consider the diversity of existing crops in a way that could be usable to inform decisions and support urban food strategies. Most studies are based on the definition of the area required to meet local consumption, obtaining a map represented as an isotropic circle around the city, without considering the site-specific pedoclimatic, geographical, and socioeconomic conditions which are essential for the development of local food supply chains. They proposed a first stage to fill this gap by combining the 'Metropolitan Foodshed and Self-Sufficiency Scenario' model, which already considers regional yields and specific land use covers with spatially explicit data on cropping patterns, soil, and topography. They used the available Europe-wide data and apply the methodology in the city region of Avignon (France), initially considering a foodshed with a radius of 30 km. Results showed that even though a theoretically-high potential self-sufficiency could be achieved for all of the food commodities consumed (>80%), when the specific pedological conditions of the area are considered, this could be suitable only for domestic plant-based products, whereas an expansion of the initial foodshed to a radius of 100 km was required for animal products to provide >70% self-sufficiency. They concluded that it is necessary to shift the analysis from the size assessment to the commodity-group–specific spatial configuration of the foodshed based on biophysical and socioeconomic features. Moreover, they discussed avenues for further research to enable the development of a foodshed assessment as a complex of complementary pieces (i.e., the 'foodshed archipelago').

The paper by Kurdyś–Kujawska et al. [12] aimed to identify the determinants of crop diversification and the impact of crop diversification on the economic efficiency of small farms in Poland. The article first provides a critical review of the literature on crop diversification, its role in stabilizing agricultural income, and its impact on economic efficiency in small farms. Secondly, the level of crop diversification was determined, and empirical research was conducted considering the economic, social, and agronomic characteristics of farms. Thirdly, the economic efficiency of farms diversifying crops was compared with farms focused on one type of production. The research material consisted of small farms participating in the Polish system of collecting and using farm accountancy data (FADN) in 2018. The level of diversification was determined using the Herfindahl-Hirschman Index. The factors influencing crop diversification were identified using the logit regression model. The Mann–Whitney U rank sum test was used to assess the significance of the differences in distributions. The research results indicated an average level of crop diversification in small farms in Poland and its regional differentiation. In addition, a statistically significant positive impact on the probability of crop diversification in small farms in Poland was found of variables such as the level of exposure of agricultural production to atmospheric and agricultural drought, the location of the farm in the frost hardiness zone, and a statistically significant negative impact of the value of its fixed assets. The existence of significant differences in the level of economic efficiency of farms diversifying crops and farms focused on one profile of agricultural production was demonstrated.

The study by Klimek-Kopyra et al. [13] assessed the effect of biochar produced from sunflower husks on soil respiration (SR), soil water flux (SWF), and soil temperature (ST), depending on its dose and different soil cover (with and without vegetation) in Poland. Moreover, the seed yield was assessed depending on the biochar fertilization. The SR, ST, and SWT were evaluated seven times in three-week intervals during two seasons over 2018 and 2019. The results indicated that the time of biochar application had a significant effect on the evaluated parameters. In the second year, significantly ($p < 0.005$) higher soil respiration (4.38 µmol s^{-1} m^{-2}), soil temperature (21.2 °C), and the level of water net transfer in the soil (0.38 m mol s^{-1} m^{-2}) compared to the first year were observed. The most effective biochar dose regarding SR and soybean yield was 60 t ha^{-1}, but a more comprehensive cost-benefit analysis is needed to recommend large-scale biochar use at this dose.

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

References

1. Tan, L.; Tran, T.; Loc, H. Soil and Water Quality Indicators of Diversified Farming Systems in a Saline Region of the Mekong Delta, Vietnam. *Agriculture* **2020**, *10*, 38. [CrossRef]
2. Udawatta, R.; Gantzer, C.; Reinbott, T.; Wright, R.; Robert, P.; Wehtje, W. Influence of Species Composition and Management on Biomass Production in Missouri. *Agriculture* **2020**, *10*, 75. [CrossRef]
3. Sogoba, B.; Traoré, B.; Safia, A.; Samaké, O.; Dembélé, G.; Diallo, S.; Kaboré, R.; Benié, G.; Zougmoré, B.R.; Goïta, K. On-Farm Evaluation on Yield and Economic Performance of Cereal-Cowpea Intercropping to Support the Smallholder Farming System in the Soudano-Sahelian Zone of Mali. *Agriculture* **2020**, *10*, 214. [CrossRef]
4. Vera-Aviles, D.; Suarez-Capello, C.; Llugany, M.; Poschenrieder, C.; De Santis, P.; Cabezas-Guerrero, M. Arthropod Diversity Influenced by Two Musa-Based Agroecosystems in Ecuador. *Agriculture* **2020**, *10*, 235. [CrossRef]
5. Carton, N.; Naudin, C.; Piva, G.; Corre-Hellou, G. Intercropping Winter Lupin and Triticale Increases Weed Suppression and Total Yield. *Agriculture* **2020**, *10*, 316. [CrossRef]
6. Munz, S.; Reiser, D. Approach for Image-Based Semantic Segmentation of Canopy Cover in Pea–Oat Intercropping. *Agriculture* **2020**, *10*, 354. [CrossRef]
7. Calvache, I.; Balocchi, O.; Alonso, M.; Keim, J.; López, I. Water-Soluble Carbohydrate Recovery in Pastures of Perennial Ryegrass (*Lolium perenne* L.) and Pasture Brome (*Bromus valdivianus* Phil.) Under Two Defoliation Frequencies Determined by Thermal Time. *Agriculture* **2020**, *10*, 563. [CrossRef]

8. He, D.; Ma, Y.; Li, Z.; Zhong, C.; Cheng, Z.; Zhan, J. Crop Rotation Enhances Agricultural Sustainability: From an Empirical Evaluation of Eco-Economic Benefits in Rice Production. *Agriculture* **2021**, *11*, 91. [CrossRef]
9. Dittrich, F.; Iserloh, T.; Treseler, C.; Hüppi, R.; Ogan, S.; Seeger, M.; Thiele-Bruhn, S. Crop Diversification in Viticulture with Aromatic Plants: Effects of Intercropping on Grapevine Productivity in a Steep-Slope Vineyard in the Mosel Area, Germany. *Agriculture* **2021**, *11*, 95. [CrossRef]
10. Gecaitė, V.; Arlauskienė, A.; Cesevičienė, J. Competition Effects and Productivity in Oat–Forage Legume Relay Intercropping Systems under Organic Farming Conditions. *Agriculture* **2021**, *11*, 99. [CrossRef]
11. Vicente-Vicente, J.; Sanz-Sanz, E.; Napoléone, C.; Moulery, M.; Piorr, A. Foodshed, Agricultural Diversification and Self-Sufficiency Assessment: Beyond the Isotropic Circle Foodshed—A Case Study from Avignon (France). *Agriculture* **2021**, *11*, 143. [CrossRef]
12. Kurdyś-Kujawska, A.; Strzelecka, A.; Zawadzka, D. The Impact of Crop Diversification on the Economic Efficiency of Small Farms in Poland. *Agriculture* **2021**, *11*, 250. [CrossRef]
13. Klimek-Kopyra, A.; Sadowska, U.; Kuboń, M.; Gliniak, M.; Sikora, J. Sunflower Husk Biochar as a Key Agrotechnical Factor Enhancing Sustainable Soybean Production. *Agriculture* **2021**, *11*, 305. [CrossRef]