

# CROP DIVERSITY AND SUSTAINABLE AGRICULTURE: MECHANISMS, DESIGNS AND APPLICATIONS

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Intensive monoculture agriculture has contributed greatly to global food supply over many decades, but the excessive use of agricultural chemicals (fertilizers, herbicides and pesticides) and intensive cultivation systems has resulted in negative side effects, such as soil erosion, soil degradation, and non-point source pollution<sup>[1]</sup>. To many observers, agriculture looms as a major global threat to nature conservation and biodiversity. As noted in the Global Biodiversity Outlook 4<sup>[2]</sup>, the drivers associated with food systems and agriculture account for around 70% and 50% of the projected losses by 2050 of terrestrial and freshwater biodiversity, respectively<sup>[3]</sup>.

In addition, agricultural development and modernization of agriculture has led to a decline in the total number of plant species upon which humans depend for food<sup>[4]</sup>. Currently, fewer than 200 of some 6000 plant species grown for food contribute substantially to global food output, and only nine species account for 67% of total crop production<sup>[3]</sup>. The global crop diversity has declined in past decades.

Crop species diversity at a national scale was identified as one of the most important factors that stabilize grain production at a national level<sup>[5]</sup>. A group of long-term field experiments demonstrated that crop diversity also stabilizes temporal grain productivity at field level<sup>[6]</sup>. Therefore, maintaining crop diversity at both national and field levels is of considerable importance for food security at national and global scales.

Crop diversity includes temporal (crop rotation) and spatial

diversity (e.g., intercropping, agroforestry, cultivar mixtures and cover crops) at field scale. Compared to intensive monocultures, diversified cropping systems provide additional options to support multiple ecosystem functions. For instance, crop diversity may increase above- and belowground biodiversity, improve yield stability, reduce pest and disease damage, reduce uses of chemicals, increase the efficiency of the use land, light water and nutrient resources, and enhance stress resilience in agricultural systems.

To highlight advances in research and use of crop diversity, from developing and developed countries, we have prepared this special issue on “Crop Diversity and Sustainable Agriculture” for *Frontiers of Agricultural Sciences and Engineering*, mainly focusing on intercropping.

Intercropping, growing at least two crops at the same time as a mixture, for example, in alternate rows or strips, is one effective pathway for increasing crop diversity at the field scale. Over recent decades, there have been substantial advances in terms of understanding of processes between intercropped species and applications in practice. There are 10 articles in this special issue including letters, opinions, review and research articles with contributions from Belgium, China, Denmark, France, Germany, Greece, Italy, the Netherlands, Spain, Switzerland, UK, and Mexico etc.

The contributors are internationally-active scientists and

agronomists contributing to intercropping research and extension. For example, Antoine Messean is coordinator of the EU H2020 Research project DiverIMPACTS “Diversification through rotation, intercropping, multiple cropping, promoted with actors and value chains towards sustainability”. Eric Justes is coordinator of the EU H2020 Research project ReMIX “Redesigning European cropping systems based on species mixtures”. Maria Finckh has worked on crop cultivar mixture and organic agriculture over many years. Henrik Hauggaard-Nielsen has outstanding expertise in intercropping research and applications, moving from detailed studies on species interactions in intercropping to working with farmers and other stakeholders to make intercropping work in practical farming. In addition to these established scientists, young scientists who have taken an interest in intercropping also contribute to the special issue, including Wen-Feng Cong, Yixiang Liu, Qi Wang, Hao Yang and others.

The first contribution to this special issue addresses how to design cropping systems to reach crop diversification, with Wen-Feng Cong and coworkers (<https://doi.org/10.15302/J-FASE-2021392>) considering that it is necessary to optimize existing and/or design novel cropping systems based on farming practices and ecological principles, and to strengthen targeted ecosystem services to achieve identified objectives. In addition, the design should consider regional characteristics with the concurrent objectives of safe, nutritious food production and environmental protection.

The benefits of crop diversification have been demonstrated in many studies. Wen-Feng Cong and coworkers describe the benefits of crop diversification at three scales: field, farm, and landscape. Hao Yang and coauthors reviewed the multiple functions of intercropping. Intercropping enhances crop productivity and its stability, it promotes efficient use of resources and saves mineral fertilizer, controls pests and diseases of crops and reduces the use of pesticides. It mitigates climate change by sequestering carbon in soil, reduces non-point source pollution, and increases above- and belowground biodiversity of other taxa at field scale (<https://doi.org/10.15302/J-FASE-2021398>).

Eric Justes and coworkers proposed the “4C” framework to help understand the role of species interactions in intercropping (<https://doi.org/10.15302/J-FASE-2021414>). The four components are competition, complementary, cooperation (facilitation) and compensation, which work often simultaneously in intercropping. Hao Yang and coworkers used the concept of diversity effect from ecology to understand the contribution of complementarity and selection effects to

enhanced productivity in intercropping. The complementarity effect consists of interspecific facilitation and niche differentiation between crop species, whereas the selection effect is mainly derived from competitive processes between species such that one species dominates the other (<https://doi.org/10.15302/J-FASE-2021398>). Also, Luis Garcia-Barrios and Yanus A. Dechnik-Vazquez dissected the ecological concept of the complementarity and selection effects to develop a relative multicrop resistance index to analyze the relation between higher multicrop yield and land use efficiency and the different ecological causes of overyielding under two contrasting water stress regimes (<https://doi.org/10.15302/J-FASE-2021412>).

Odette Denise Weedon and Maria Renate Finckh found that composite cross populations, with different disease susceptibilities of three winter wheat cultivars, were moderately resistant to brown rust and even to the newly emerged stripe rust races prevalent in Europe since 2011, but performance varied between standard and organic management contexts (<https://doi.org/10.15302/J-FASE-2021394>).

Comparing the performance of intercrops and sole crops is critical to make a sound evaluation of the benefits of intercropping and assess interactions between species choice, intercrop design, intercrop management and factors related to the production situation and pedoclimatic context. Wopke van der Werf and coworkers review some of the metrics that could be used in the quantitative synthesis of literature data on intercropping (<https://doi.org/10.15302/J-FASE-2021413>).

Interspecific interactions provide some of the advantages of intercropping, and can be divided into above- and belowground interactions. Aboveground interactions can include light and space competition, which is influenced by crop species traits. Root exudates are also important in interspecific interactions between intercropped or rotated species. Qi Wang and coworkers estimated the light interception of growth stage of maize-peanut intercropping and corresponding monocultures, and found that intercropping has higher light interception than monoculture, and increasing plant density did not further increase light interception of intercropping (<https://doi.org/10.15302/J-FASE-2021403>). Yuxin Yang and coworkers reported that the root exudates of fennel (*Foeniculum vulgare*) can reduce infection of tobacco by *Phytophthora nicotianae* via inhibiting the motility and germination of the spores of the pathogen (<https://doi.org/10.15302/J-FASE-2021399>).

Focusing on the application of intercropping, Wen-Feng Cong

and coworkers formulated species recommendations for different regions of China for different crop diversity patterns and crop species combinations. These authors also suggested three steps for implementing crop diversification on the North China Plain. Although there are multiple benefits of crop diversification, its extension and application are hindered by various technical, organizational, and institutional barriers along value chains, especially in Europe. Based on the findings of the European Crop Diversification Cluster projects, Antoine Messéan and coworkers suggested that there needs to be more coordination and cooperation between agrifood system stakeholders, and establish multiactor networks, toward an agroecological transition of European agriculture (<https://doi.org/10.15302/J-FASE-2021406>). In addition, Henrik Hauggaard-Nielsen and coworkers report the outcomes of a workshop for participatory research to overcome the barriers

to enhanced coordination and networking between stakeholders (<https://doi.org/10.15302/J-FASE-2021416>).

Intercropping, though highly effective in labor-intensive agriculture, may be difficult to implement in machine-intensive, large-scale modern agriculture because appropriate large equipment is not commercially available for planting and harvesting various crop mixtures grown with strip intercropping<sup>[6]</sup>. Thus, the appropriate machinery will need to be developed for further practical application in large-scale agriculture.

As the guest editors, we thank all the authors and reviewers for their great contributions to this special issue on “Crop Diversity and Sustainable Agriculture”. We also thank the FASE editorial team for their kind supports.

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Dr. Long Li, Professor at China Agricultural University. He has continuously worked on intercropping research and application for more than 30 years in terms of interspecific competition and facilitation on nutrients between crop species, overyielding, root distributions, rhizosphere processes, phosphorus mobilization, biological N<sub>2</sub> fixation and long-term soil fertility effects.

His research interests are to integrate the research knowledge of agricultural intercropping into more broaden context in ecology. At the same time, he has endeavored to understand how crop diversity enhance ecosystem service and functions in agroecosystems. He also has tried his best to apply the research knowledge of intercropping to farmers' fields in practice.



Dr. Wopke van der Werf, Associate professor at the Centre for Crop Systems Analysis, Wageningen University. His work combines statistical and modeling approaches with experiments to gain deeper understanding in the functioning of agroecological systems. Intercropping has had his great interest since the 1990s when his first PhD student studied biological control of

cotton aphid in wheat-cotton intercrops in China. It is his ambition to help unlock the potential of intercropping for developing a more environmentally benign and productive agriculture. This unlocking requires insight in how and why intercropping works or can work in different production situations across the globe.