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Intercropping for sustainability: Research developments and their application

An agricultural diversification trial by patchy field arrangements at the landscape level: The landscape living lab "patchCROP"

By KATHRIN GRAHMANN[1], MORITZ RECKLING[1], IXCHEL HERNANDEZ-OCHOA[2]
and FRANK EWERT[1,2]

[1]*Leibniz Centre for Agricultural Landscape Research (ZALF), Germany*
[2]*University of Bonn, Institute of Crop Science and Resource Conservation (INRES), Germany*

Summary

This paper addresses challenges of and opportunities to design novel agricultural landscapes by using digital tools as well as implementing experimental infrastructures to investigate and test them scientifically. We discuss the experimental design of the newly implemented landscape experiment named patchCROP at the Leibniz Centre for Agricultural Landscape Research (ZALF) in Germany. The paper presents the research questions and selected (digital) measurements within the patchCROP experiment. The objective of this living lab is to reduce chemical-synthetic pesticide use, to promote biodiversity and to improve resource use efficiency by reducing the field size and by introducing site-specific, diverse crop rotations that are adapted to the heterogeneous soil conditions. For this purpose, new field arrangements are investigated on-farm and are hereafter called "patches", which are small structured field units, a subdivision of the large heterogeneous field into smaller and more homogenous units that correspond to the yield potential of the site.

Key words: Configurational crop heterogeneity, crop rotation, digital agriculture, patch cropping

Introduction

Smart use of agricultural landscapes should account for spatial heterogeneities of soils and temporal crop diversification. This could support higher resource use efficiency, external input independency and stable yields while at the same time, optimizing provision of ecosystem services and mitigating ecosystem damage (Benton *et al*., 2003; Maskell *et al*., 2019). Agricultural diversification was reported to improve ecosystem services on many occasions and levels: the improvement of beneficial insect habitat, better root establishment and hence better soil structure, pest repression, or increased soil suppressiveness among many other benefits are related to different applications of agricultural diversification (Petit *et al*., 2018; Davis *et al*., 2012; Veen *et al*., 2019). Numerous studies have reported the advantages and progress of new technologies in the agricultural context, like wireless, internet based monitoring systems which screen landscape parameters in real time with sensors in soil, water and air (Aquino-Santos *et al*., 2011; Vuran *et al*., 2018; Diacono *et al*., 2013). The acquired data and information from different levels and disciplines can be combined with artificial intelligence and machine learning approaches and provide synergies with emerging digital technologies, leading to recommendations for a sustainable adaptation of the cropping system (Bacenetti *et al*., 2020; Chlingaryan *et al*., 2018; Talaviya *et al*., 2020). New field arrangements with significantly smaller field sizes and new field shapes that replace large uniform and sole cropped fields and advancements in the use of ecological principles and new technologies offer an opportunity to redesign agricultural landscapes of the future and to reduce chemical-synthetic pesticide applications (Batáry *et al*., 2017; Segoli & Rosenheim, 2012; Bosem Baillod *et al*., 2017). There is an urgent need for an experimental platform that assesses the functioning of innovative field technologies and combines them with multiple scientific measurements of sustainability indicators to simultaneously progress in the design of future cropping systems.

ZALF is an internationally recognized research centre that focusses on the understanding of agricultural landscapes of the future by achieving innovative, site-specific cropping methods that combine food production with the protection of biodiversity and maintenance of ecosystem services. A major research plan entitled "Sustainable agricultural systems through spatio-temporal diversification at landscape level" was initiated by ZALF in 2019. Within this framework, a landscape experiment was designed from a multidisciplinary perspective to address multiple-level problems including soil heterogeneity, climate change, system resilience, and dependency on external inputs, especially chemical synthetic pesticides. This resulted in the implementation of a long-term on-farm experiment, named patchCROP, which is located within the typical agricultural landscapes of Eastern Brandenburg. The patchCROP experiment sets one of its sustainability foci on chemical pesticide reduction by increasing compositional and configurational heterogeneity of crops, fields and in future also agricultural landscapes. The overall aim of this experiment is to envisage the processes and mechanisms of agricultural diversification implemented at different spatial (field size and shape, site-specific management, crop species) and temporal scales (temporal shifts-planting date, spring and winter crops, crop rotation, management activities) on the multifunctional response of agroecosystems (e.g. in terms of crop growth, yield, input reduction, resource use and efficiency and biodiversity (Sirami *et al*., 2019; Hatt *et al*., 2018; Hufnagel *et al*., 2020)). For the purpose of spatial diversification or likewise configurational heterogeneity (Fahrig *et al*., 2011), new field arrangements, i.e. "patches" are investigated. Patches are defined as small-structured field units with homogeneous site characteristics and spatially adapted management. The patchCROP experiment is a long-term experimental infrastructure of ZALF which was recently implemented in April 2020 and is, to our knowledge, the first approach worldwide to put small-scale and site-specific cropping into practice through on-farm patch cropping.

Materials and Methods

The experimental approach and design for the landscape experiment are newly designed field arrangements within a 70 ha large field surrounded by more than 700 ha of agricultural fields (Fig. 1). Site-specific small structured field patches of 72 m × 72 m size were organised in two different yield potential zones through an automated cluster analysis of the entire field using 10 years of yield maps, soil value number, soil organic matter content and apparent electrical resistance in the top soil (0–25 cm; Donat *et al*., 2020). A specific crop rotation was developed in each yield potential zone (Table 1) based on expert knowledge and crop rotation restrictions. The field is characterised by very heterogeneous soil conditions with varying soil texture and topography.

In addition, three different land use intensities were implemented with varying pesticide use reduction strategies, partly containing perennial flower strips to promote landscape biodiversity. The first land use intensity comprised business as usual with conventional pesticide application. The second one uses flexible, and crop dependent approaches to reduce pesticides and the third one is similar to the second land use intensity but with additional 12 m wide flower strips next to the patches with the aim of additionally supporting natural enemies and pest suppression in the neighbouring crops. The decision making on strategies that may reduce the overall use on chemical-synthetic pesticides is accompanied by regular exchange and guidance though experts of the Federal Research Centre for Cultivated Plants (Julius-Kühn Institute).

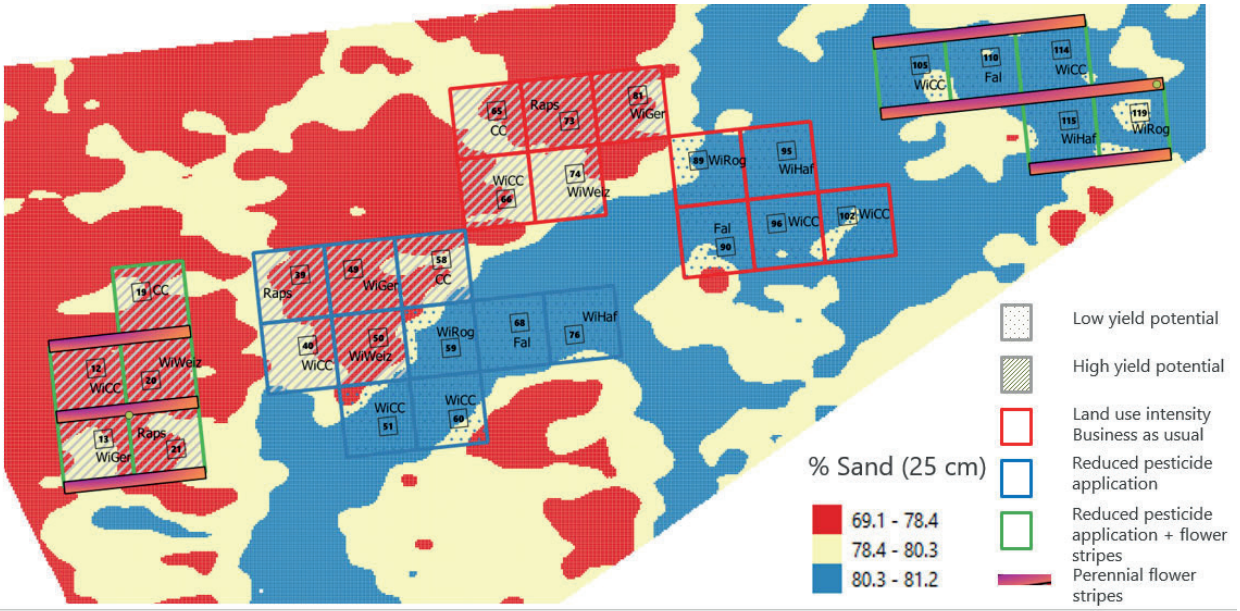

Fig. 1. Experimental site and setup of patchCROP. Soil texture map with a resolution of 2 m × 2 m was created through data of Geophilus soil scanning in March 2020. Patches with varying yield potential zones and land use intensities are depicted.

Table 1. *5 year crop rotation for each yield potential zone (CC= cover crop)*

Yield potential	1st year	2nd year	3rd year	4th year	5th year
High	Rapeseed	Barley	CC-Soybean	CC-Maize	Wheat
Low	CC-Sunflower	Oats	CC-Maize	Lupin	Rye

Three conceptual pillars were applied simultaneously in the research and development process of the experimental design. First, the inclusion of the landscape context using agricultural system research approaches and comprehensive background data. Second, a provision of a living lab that simultaneously accommodates interdisciplinary research, monitoring of soil, crop, and environmental data and demonstration activities. And lastly, an involvement of co-design and co-innovation methods that ensures innovative research approaches and guarantees a high level of engagement with farmers' needs and new technologies' implementation potentials.

Results and Discussion

patchCROP is producing information that facilitates a site-specific, diversified and sustainable land use management in agricultural landscapes by identifying local management zones and effects between neighbouring field crops. It also contributes to elucidating the interactions between spatial soil variability, crop yields and their environment. The implementation of patchCROP established a research platform for forward-looking technologies. The possibilities and impacts of visionary technologies like multidimensional sensing systems, internet of (underground) things and robotics for precision agriculture can be evaluated from three perspectives: crop physiological, ecological (including soil and biodiversity) and technological.

This is being achieved through the following specific objectives:

1. Analysis of the effects of site-specific, diversified land use and management practices on the resilience and stability of the cropping system;
2. Promotion of biodiversity in the agricultural landscape through diversified land use patterns of crop rotation and crop species in the field and the use of landscape elements that strengthen agro-ecological functions;
3. Minimize the use of chemical synthetic pesticides in agriculture by promoting the benefits of spatial and temporal diversification within the agricultural landscape;
4. Long-term reduction in the application of mineral fertilizers through improved resource use;
5. Successful use of modern, automated or sensor-controlled technology for site-specific, patchy cropping arrangements and to reduce labour costs and use of big machinery.

In addition to manual crop and soil measurements like leaf area index, NDVI, plant height, biomass and grain yield or volumetric moisture content of the top soil, several digital tools were installed in order to monitor, measure and answer important research questions. Soil sampling and measurement campaigns include soil nutrient surveys, as well as the assessment of structural and hydrological soil properties. Proximal sensing was applied with different soil scanners, and remote sensing is conducted biweekly with two different cameras. Digital yellow traps were installed in rapeseed for the monitoring of pests and beneficial insects. A LoRa (Long Range Wide Area) soil sensing system was put into operation to receive real-time *in situ* information on soil-water processes through wireless communication. In order to account for biodiversity measurements, beneficial insects are monitored with barber tarps and birds are monitored continuously in the experiment and neighbouring fields.

Preliminary results of the summer cropping cycle in 2020 are presented to show potential applications of long-term comparison for plant performance with different yield potential zones (Fig. 2) and land use intensities (Fig. 3). Average soil moisture content in the topsoil was higher in the high yield potential zone over the entire cropping cycle (Fig. 2). As sand content is higher in the low yield potential patches (Fig. 1), water holding and storage capacity of the soil might be reduced leading to lower soil moisture. This negatively affected biomass production of grain maize (Fig. 3). Conventional pesticide management led to highest biomass gains in both yield potential zones compared with reduced pesticide application and in combination with flower strips.

However, we are aware of potential risks and challenges that this novel landscape experiment implies. As there are no real replicates yet, geostatistical approaches are needed for robust statistical data analysis (Zhang *et al*., 1994). Also, the patch size is now determined and limited to the size which available agricultural machinery can manage. In future, accessible field robotics may allow the size and even form of the patches to be changed, which increases technical feasibility and contributes to sustainable intensification (Wegener *et al*., 2019).

Conclusions and Outlook

patchCROP serves as an experimental field infrastructure that provides the space and scientific framework to test digital tools and cropping systems of the future that support sustainable agricultural practice. It provides the opportunity to obtain systematic analyses of ecosystem services delivered from agricultural landscapes by compartmentalization of large fields into small-structured field units. patchCROP offers the collection of data required for complex agricultural system models and future crop models that manage field robotics. We cordially invite the scientific community to take action in this interdisciplinary and innovative project and engage the collaboration with research from many disciplines to continue working on the development, support and implementation of new digital technologies in patchCROP.

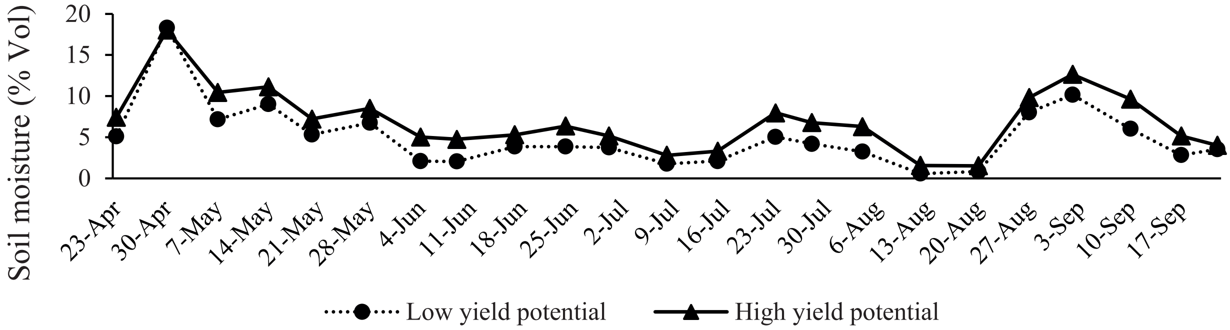

Fig. 2. Volumetric soil moisture content (%) during the summer cropping cycle in 2020 in the top soil for high and low yield potential patches (n=15) at the patchCROP experiment in Tempelberg, Germany.

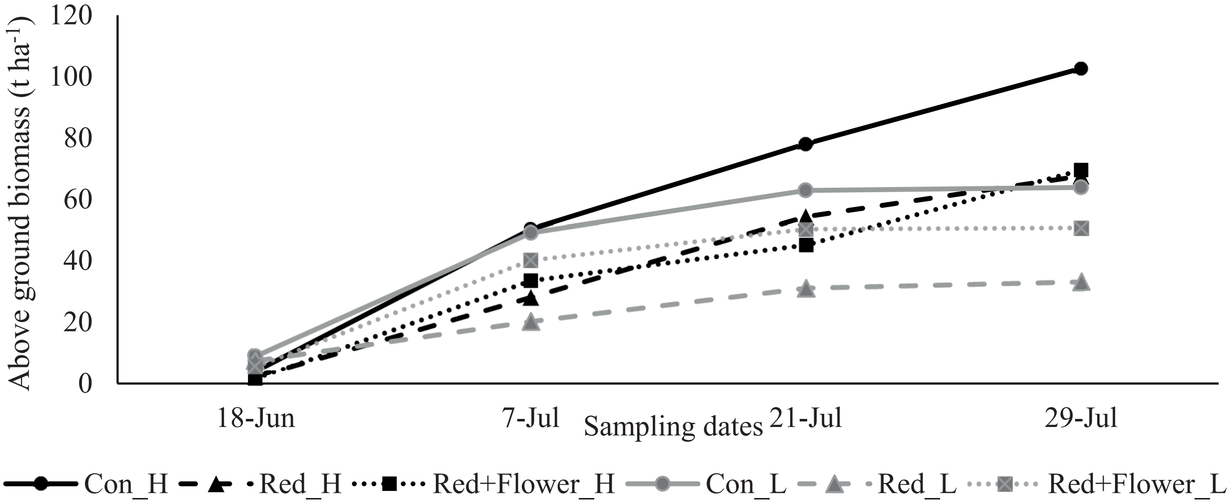

Fig. 3. Biomass gain of grain maize of four cutting dates during the summer cropping cycle in 2020 for three different land use intensities (Con= business as usual, Red= reduced pesticide application, Red+Flower= reduced application and flower strips) and two yield potential zones (H=high, L=low yield potential) at the patchCROP experiment in Tempelberg, Germany.

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