Dogo Rangsang Research Journal **UGC Care Group I Journal**
ISSN: 2347-7180 **Vol-09 Issue-03 September-December 2019**

DISCUSSION PAPER: SUSTAINABLE INCREASE OF CROP PRODUCTION THROUGH IMPROVED TECHNICAL STRATEGIES, BREEDING AND ADAPTED MANAGEMENT – A EUROPEAN PERSPECTIVE

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ABSTRACT

During the next decade it will be necessary to develop novel combinations of management strategies to sustain- ably increase crop production and soil resilience. Improving agricultural productivity, while conserving and en- hancing biotic and abiotic resources, is an essential requirement to increase global food production on a sustainable basis. The role of farmers in increasing agricultural productivity growth sustainably will be crucial. Farmers are at the center of any process of change involving natural resources and for this reason they need to be encouraged and guided, through appropriate incentives and governance practices, to conserve natural ecosys- tems and their biodiversity, and minimize the negative impact agriculture can have on the environment. Farmers and stakeholders need to revise traditional approaches not as productive as the modern approaches but more friendly with natural and environmental ecosystems values as well as emerging novel tools and approaches ad- dressing precise farming, organic amendments, lowered water consumption, integrated pest control and benefi- cial plant-microbe interactions. While practical solutions are developing, science based recommendations for crop rotations, breeding and harvest/postharvest strategies leading to environmentally sound and pollinator friendly production and better life in rural areas have to be provided.

Introduction :To feed a global population forecasted to grow to over nine billion by 2050, enhanced agricultural production will be of utmost importance. Ensuring food security and feed availability must clearly increase to meet the future demands of a more affluent world population (FAO, 2011). This places great strain on major agricultural producing countries across all continents, since the available arable land is limited, and cli- mate change provides less favorable conditions for plant production in many agricultural areas.

In fact, among environmental triggers, drought is the principal factor restraining global agricultural production (Manavalan et al., 2009). Cur- rently, about 40% of the world population lives in regions where water is a limited resource, specifically aggravating and restricting its use in ag- riculture (UNESCO, 2009; Mekonnen and Hoekstra, 2016). Many global agricultural regions including China, India and the USA, the world's larg- est grain producers, are already facing serious water shortages (Zhao et al., 2010).

Improving agricultural productivity, while conserving and enhanc- ing water resources, is an essential requirement to increase global food production on a sustainable basis. The role of farmers in increasing agricultural productivity growth sustainably will be crucial. Farmers are at the center of any process of change involving natural resources and for this reason they need to be encouraged and guided, through appropriate incentives and governance practices (see Fig. 1), to conserve nat- ural ecosystems and their biodiversity, and minimize negative impacts agriculture can have on the environment (FAO, 2017).

One way of increasing agricultural production might be to breed, with or without GMO, for higher yielding crops that require less water, less space, have better nutrient usage and are adapted to climate change (Głowacka et al., 2018), but this is not the only way to improve plant production systems. Although we have considerably improved productivity from conventional to integrated agricultural practice, striv- ing to balance nutrient cycles adapted to demands of the crops, and have new crop varieties available, we are still depending too much on monocultures in poor rotation schemes, synthetic fertilizers and pesti- cides that lead to uncoupling of energy and matter fluxes in the produc- tion system and stress the soil environment (Schröder et al., 2008).

At the same time, beneficial plant microbe interactions are still an until now unexploited ecosystem service for plant production. Plant di- versity in crop rotations supports and selects the microbial community in the rhizosphere. However, when this diversity is being replaced by uniformity, it is also reflected in the agricultural market place, and in human diets (IPES-Food, 2016). In fact, homogenization of agricultural production systems, e.g. by intensification and restricted use of plant va- rieties, is one of the greatest causes of agricultural biodiversity loss, through genetic erosion and the increasing levels of genetic vulnerabil- ity of specialized crops (SCBD, 2018).

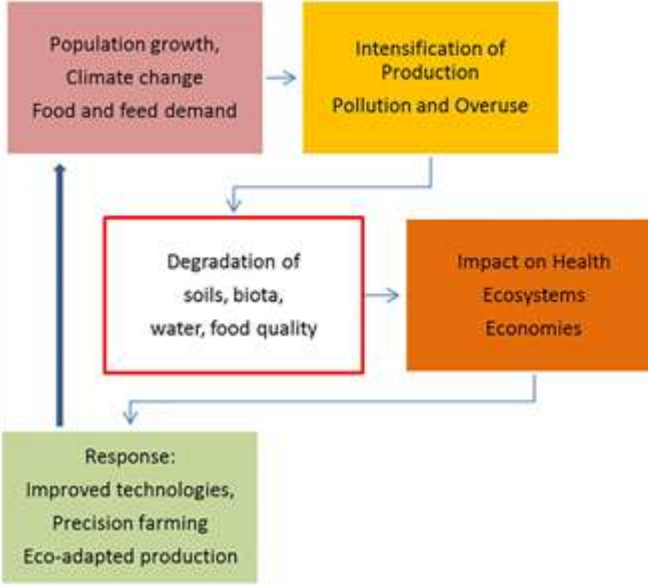


Fig. 1. Identification of problems and future options in agriculture. In analogy to Mateo-Sagasta et al. (2017), this flow chart utilizes analogies to the UN DPSR model of indicators to characterize problems and options.

Hence, a change in paradigm is needed to keep the valuable produc- tion base, our soils, healthy, and to unleash so far hidden processes that will help increase production of food and biomass at good quality. To guarantee food supply and to ensure continued food security, environ- mental, economic, social and cultural aspects of sustainability should all be covered in future development of agricultural systems: environ- mental, economic, social and cultural (Keding and Schneider, 2013). In- novative strategic food systems must target enhanced agricultural production technologies, food processing and preservation innovations, environmental issues, and ultimately human health (Godfray and Garnett, 2014). Albeit a problem of global relevance, and being recognized by the scientific community, political and societal solutions are pursued differently in different continents and major economic areas of the world. The “ideal agriculture” may depend of many various fac- tors such as the social context in which farmers are living or different environments. The present paper may therefore be a bit restricted, since we gather expertise from the direct experience with the European situation, and the agro-scientifical decision makers of the EU. Still, as in other fields of scientific endeavor, many of the conclusions drawn may be generally valid, of common interest and find counter- parts in regions outside of Europe. The present opinion paper discusses the above mentioned options for improved crop production under sce- narios of climate change and soil degradation and proposes innovative solutions for the complex problem.

1.1. A vision for ideal agriculture

While it is generally accepted that land has a value to be paid for, the same is not true for the value of soil. In our general perception it seems that good quality soil is taken for granted (Keesstra et al., 2016). But it is clear that soils are not renewable and deliver essential services. Hence, within the framework of the 17 UN Sustainable Development Goals (SDGs) (https://sustainabledevelopment.un.org/sdgs), soil manage- ment and restoration are key issues (Ussiri and Lal, 2018), and there is no doubt that soils have to be well treated to keep them productive (Supplementary Table 1).

In such a context, agricultural practice is the main trigger to conserve and improve soil functions on a large scale, indispensable to adapt the production systems to the requirements of future generations. Organic farming emerged as a new sector of agrobusiness during last decades (Clark et al., 1999). Designed to produce high-quality food, while keep- ing inputs of resources (water, energy, fertilizers, pesticides etc.) to a minimum, it takes advantage of soil, microbial and plant processes that contribute towards crop stability and resource efficiency. Moreover, organic farming targets to cycle nutrients and reduce losses, rely more on ecosystem services than on artificial inputs, thus contributing in manifold ways to strategic EU policies (Smith et al., 2015). The public perception of such farming systems in terms of food quality, food safety and environmental friendliness/sustainability is positive. However, yields are lower than in integrated plant production systems, which often means that food based on organic agriculture is more expensive than food from other types of farming. The increasing demand for food, also organically produced, due to the population increase de- scribed above will lead to yet higher prices for gross markets and consumers. And in terms of nutrient and water acquisition by crop plants, especially under constraints such as nutrient deficient soils, increasing frequency of droughts due to climate change, or system-inherent limita- tions such as the typical lack of livestock (and return of manure) in Europe (EC, 2011), enhancement of the production efficiency of our farming systems is a timely demand.

At the same time, integrated production systems have made great progress in adopting technical improvements like remote sensing, pre- cision farming, computerized pesticide application, wide tires on com- bines and tractors, adapted fertilizer application, to name but a few.

Similar to organic farming, integrated farmers have developed schemes for the reduced use of agrochemicals and pesticides.

But, although well developed and in many ways successful, both production systems have some shortcomings, and so it might be timely to merge the best of both worlds, integrated and organic, to boost agri- cultural productivity and soil health. In this context, biological interactions are key.

1.2. A possible solution

Future sustainable agriculture should be open to adopt central man- agement practices of both, conventional and organic farming by com- bining low input principles of organic farming with precise cultivation, tillage, fertilizer application, pest control and water reuse (see Fig. 2).

The central driving force in organic farming is an elaborate crop ro- tation scheme, set up to regenerate nutrient pools of the topsoil and prevent erosion and nutrient losses (Schröder et al., 2008). It is well-known that a high diversity plant cover is likely to be self-sustainable due to in- teractions developing between the different plant species or between plants and microorganisms in terms of nutrient use and cycling, com- pared to monocultures and crop rotations with low crop diversity that exhaust soil, requiring therefore higher maintenance costs (Fox, 2003). To achieve self-sustainability, novel management regimes need to manipulate soil and plant microbial communities to best effect, while maximizing positive ecological interactions and enhancing eco- system services (Spehn et al., 2005). In this way, strategic soil manage- ment reduces costly and environmentally damaging chemical inputs in each of these systems (Tilman et al., 2002). Such a demand has been specifically voiced in EU research calls, recognizing that agrobiodiversity is essential for the resilience, adaptability and productivity of disturbed arable land.

To achieve this, it will be necessary that scientists from different fields closely cooperate with farmers, key stakeholders and end-users such as, seed producers, agri-biotech firms, conservation agencies and water management specialists, integrating them from planning to deliv- ery. Ground-breaking research aimed at developing management rec- ommendations is required, in different cropping systems, to improve the macro- and microbial diversity of their soils, to reduce chemical in- puts, and to maximize positive interactions between organisms. Such an approach might be worth the strain since by studying and improving ro- tational croplands across Europe, novel solutions to improve resilience and productivity might be found.

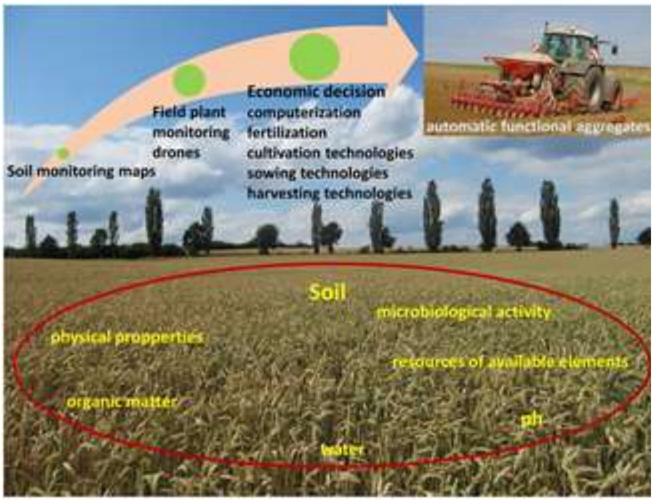


Fig. 2. On the way to economically and ecologically sound decisions, future farm management has to access all available field data and translate them into operating procedures for multifunctional aggregates.

The ultimate aim is to provide novel and intuitive management rec- ommendations to support Common Agricultural Policy (CAP) instru- ments and foster improved agricultural and environmental conditions across the EU and affiliated countries.
Hence, major objectives of such an approach might include, to

- combine cutting-edge interdisciplinary breeding technology relevant to water management, plant nutrient acquisition and beneficial plant microbe symbioses for selection of novel varieties to the field;
- manipulate/manage rhizospheres to generate integrated rhizotechnologies that optimize exploitation of plant-microbe inter- actions in crop production
- predict effects of improved nutrient and water efficiency (that are un- derstood at the micro-scale) due to rhizosphere manipulation/ rhizotechnologies on crop/plant performance at the macro-scale;
- close the gap between integrated and organic farming by adopting the best methods of both systems
- improve weed and pest control by utilizing biorational pesticides, new combinations, site-specific plant protection, improved post-harvest procedures, and provide a pollinator-friendly environment,
- perform field scale demonstration studies for formulation of agropolicy decisions, and
- deliver a toolbox for surplus productivity, translated to practical terms, for farmers, stakeholders and decisionmakers.

In the following we will describe the influence of the most crucial factors for surplus productivity at small ecological footprints within a European perspective.

1. Reclaimed water for irrigation

The main factor determining the amount of plant biomass is water. To meet food demands by 2050, worldwide crop production needs to increase by 70% (Wu and Ma, 2015). Increases in irrigation water con- sumption to meet those food demands have been estimated to be 50% in developing countries and 16% in developed countries (Fischer et al., 2007).
Intensification in water consumption can cause biodiversity loss, soil salinization; soil flooding, loss of complementary services, inequality between users, increases in vulnerability, and the deterioration of water sources and ecosystems.
On the other hand, agriculture itself contributes to water pollution, especially with biogenic compounds (nitrogen, phosphorus). In the last 20 years, a new class of agricultural pollutants has emerged in the form of veterinary medicines (antibiotics, vaccines and growth pro- moters). In the European Union, 38% of water bodies are significantly under pressure from agricultural pollution (WWAP, 2015). Pollution of waters limits the possibilities of their use and at the same time forces to bear the costs associated with their treatment. Pollution also reduces the possibility of counteracting water scarcity by reusing it, for example in agriculture.
Since sustainable agriculture focuses on the development of prac- tices that are safe for the environment (Alberola et al., 2008), manage- ment of water resources is perceived as a set of measures to increase crop production while minimizing water losses (Mancosu et al., 2015). Careful wastewater reuse for crop irrigation may eventually represent an efficient practice to comply with water scarcity and climate changes in drought affected regions, but also with water use competition prob- lems

in the water-energy-food-ecosystems nexus, as discussed by many EU directives and policy reports (Venghaus and Hake, 2018). However, there are many caveats connected to this topic. Reclaimed wastewater is currently already used for crop irrigation in many regions of the world including the Mediterranean (Hettiarachchi and Ardakanian, 2016; Christou et al., 2017; De Gisi et al., 2017). For large scale application, the effluents from municipal wastewater treatment plants are considered useful, since they have the necessary flow and nutrients (nitrogen and phosphorous necessary for crop growth), while containing lower pollution loads of toxic inorganic and organic chemicals (as in the case of industrial effluents).

There are several factors that influence the adoption of wastewater reused applications at large scale as depicted in Fig. 3 and detailed below:

1.1. Wastewater matrix (health and environmental concerns)

Municipal wastewater treatment plants (MWWTP) collecting waste- water from combined sewers usually remove solids of different size, bio- degradable organic and inorganic compounds based on conventional processes such as mechanical (bar-screens, grit removal, sedimentation, flotation), chemical (precipitation) and biological (suspended or attached growth) with or without tertiary treatment (involving nitrogen and phosphorous removal).

For the implementation of wastewater reuse in agriculture, the elim- ination of targeted priority organic or inorganic pollutants (toxic metals) and microorganisms (bacteria, viruses, and parasites) is neces- sary in terms of health related standards needed for water handling/ storage, accumulation in crops and risks posed to human consumption (De Gisi et al., 2017; Salgot and Folch, 2018, Sapkota, 2018). Such prior- ity emerging pollutants include pharmaceuticals and personal care products (PPCPs), pesticides, industrial additives and by-products, ste- roid hormones, drugs of abuse, food additives, flame retardants and surfactants (Teodosiu et al., 2018). Even if these priority substances are present in very small concentrations, they may pose significant health hazards if not adequately monitored and removed from wastewater. In a recent review, Jaramillo and Restrepo (2017) mentioned problems that may appear after irrigation with the soil's physicochemical and microbiological parameters in close relation with the wastewater compo- sition (pH, organic matter, nutrients, salinity, toxic contaminants).

1.2. Technological developments

Advanced wastewater treatment processes have to be applied to eliminate target priority organic or inorganic pollutants that are difficult to remove within the conventional treatment stages (mechanical, chemical and biological). These processes can be coupled to MWWTPs after the conventional treatment stages and their selection may highly depend on wastewater quality, crop irrigation requirements, the avoid- ance of microbiological related risks and secondary pollution and eco- nomic considerations (Jaramillo and Restrepo, 2017; Salgot and Folch, 2018; Licciardello et al., 2018). The following treatment processes may be used standalone or combined (see also Fig. 3): Advanced oxidation processes (AOPs); Membrane based treatment processes (ultrafiltra- tion, nanofiltration, membrane bioreactors); Filtration (sand); Disin- fection (chlorination, UV radiation, ozonation, other chemical disinfectants); Constructed wetlands (Schröder et al., 2007; De Gisi et al., 2017; Vergine et al., 2017; Licciardello et al., 2018).

1.2.1. Wastewater reuse standards

The adoption of guidelines on wastewater reuse in agriculture will be very important for the advanced wastewater treatment selection process and threshold values to be established for the microbiological indicators, turbidity, suspended solids, nutrients and other quality indi- cators (such as concentrations of heavy metals, priority organic pollut- ants, biochemical oxygen demand- BOD, etc.). Water reuse standards are available in some EU countries (Cyprus, France, Greece, Italy, Portugal, Spain), and a recent EU common implementation strategy has been endorsed by the EU Water Directors (EC, 2016). Moreover, based on the proposal of “Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge” (Alcalde-Sanz and Gawlik, 2017), the European Parliament and the Council has proposed the European Directive on the “Regulation on minimum requirements for water reuse” (EC, 2018).

The importance of standardization for systems dealing with wastewater reuse for irrigation is also proven by other international standards as follows:

- World Health Organisation (WHO) which issued the “Guidelines for the safe use of wastewater, excreta and greywater” in 1973 with its revised versions of 1989 and 2006 (WHO, 2006);
- United States Environmental Protection Agency (U.S. EPA) (updated) guidelines for wastewater reuse (EPA, 2012);
- International Organization for Standardization (ISO), Technical Committee TC 282/SC 1 is elaborating standards for guidance on planning, operation, water quality and good practices to avoid potential adverse impacts of water reuse on public health, crops, soil and water resources (ISO/TC 282/SC 1, n.d). So far, five standards with guidelines for treated wastewater use, monitoring and adaptation of irrigation systems have been finalized: ISO 16075- parts 1, 2, 3, 4 and ISO 20419:2018, while five standards are under development (https://www.iso.org/committee/5148678/x/catalogue/).

1.2.2. Economic and stakeholder concerns

Pistocchi et al. (2018) have published a comprehensive analysis on the potential of water reuse for agricultural irrigation in the EU, mentioning that the total volumes of wastewater that in principle can be reused for irrigation are significant, this contributing to: a) reduction of water stress with approx. 10% in water-scarce regions and b) nutrient pollution mitigation. While the treatment and energy costs are minor, total costs depend significantly on infrastructure costs and the distance from the MWWTP to the irrigated land, already existent irrigation infrastructure being a benefit. Treatment costs of approx. 8 €cents/m3 and typical total costs below approx. 50 €cents/m3 are mentioned, but if treatment requirements become more stringent, treatment costs are expected to increase to 0.23 €/m3, causing total costs to shift consistently. Energy requirements for pumping reclaimed water from MWWTP to agricultural land of approx. 0.5 kWh/m3 are reported.

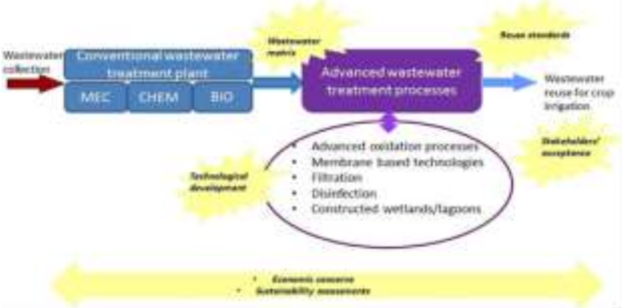


Fig. 3. Wastewater reuse for irrigation. Concept and influencing factors, as detailed in the text.

Stakeholders/end-users have different interactions with reclaimed water or with crops consumption, due to the risks of direct or indirect exposure. Farmers and irrigators are susceptible to enter in contact with reclaimed water frequently, supermarket chains and retailers also exert a role as stakeholders who impose conditions on the cultivation of crops they trade with, while the last stakeholder is represented by people consuming crops produced with irrigation wastewater (Salgot and Folch, 2018).

The current drawbacks in reuse, apart from technical and health assessment problems related to the capacity of a reclamation system to constantly obtain good quality water, refer mainly to the expectations and limitations of stakeholders (EC, 2016). Most end-users in developed and developing countries have been educated to consider wastewater as high cause of chemical and microbiological risks, and the shift towards a useful resource is not easy to implement (Saliba et al., 2018; Chhipi-Shrestha et al., 2019). Besides technologies that are essential for safe reuse, efficient communication and public participation are necessary in terms of public acceptance, commitment, support to decisions and increased awareness of reuse schemes benefits and risks.

1.3. Sustainability assessments

The selection of wastewater reuse processes for agricultural irriga- tion should consider complex criteria involving technical, environmen- tal and economic aspects to ensure a sustainable technological option, i.e.: a) environmental assessment instruments (life cycle assessment, environmental impact assessment, carbon and water footprint, multi criteria assessments, etc.), b) technical and health performance indica- tors (removal efficiencies, specific energy consumption, risk assess- ment, reagent quantities, etc.), and c) economical evaluation tools (life cycle costing, cost-benefit analysis) (Meneses et al., 2010; EC, 2016; Akhoundi and Nazif, 2018). Of course, the selection of any specific as- sessment instrument must be based on data availability, legal and ad- ministrative frameworks, monitoring program characteristics, and stakeholder involvement.

2. Novel breeding techniques for adapted plants

During the recent dry summer of 2018, farmers and consumers in northern and central Europe had to learn that impact of drought on crop yield depends on the stress onset, duration and intensity as well as on the response of the crop. Shortage of water either at the emer- gence or during the early establishment can be lethal, while stress dur- ing the reproductive phase generally causes high yield and quality reduction. For example, barley (Wie et al., 2018) but also groundnut (Reddy et al., 2015) suffer from greater yield losses when drought oc- curs during flowering and pod formation. In maize, yield is often re- duced two to three times more when water deficit coincides with flowering, compared with other growth stages (Grant et al., 1989). Also, varieties of wheat benefit differently from their symbiosis with arbuscular mycorrhizal fungi (AMF) under drought stress (Zhou et al., 2015).

In general, plant species/varieties respond to drought stress accord- ing to timing and intensity of water deficits. A clear distinction should be made between traits that help plants to survive severe water stress (drought survival) and traits that mitigate yield losses in crops exposed to mild water stress (drought adaptation) (Textbox/Fig. 4). Modern breeding is mainly searching solutions for the latter case (for a compre- hensive overview see Khan et al., 2016, Luo et al., 2019).

2.1. The molecular basis of drought stress adaptation

Several candidate genes have been characterized through forward and reverse genetics for their involvement in the adaptation to drought stress. Among them, genes involved in the metabolism, signaling and lo- calization of ABA play a fundamental role in the regulation of stomata movement. For instance, calcium-dependent protein kinases (CDPKs) mediate stomatal movement under drought stress (Zou et al., 2010), while membrane localized transporters of the ABC family take care of the correct localization of ABA during water stress response (Kang et al., 2010). Furthermore, transcription factors belonging to ABF, MYBF and MYCF families are critical in the regulation of downstream gene expression and the organization of stress response pathways (Osakabe et al., 2014).

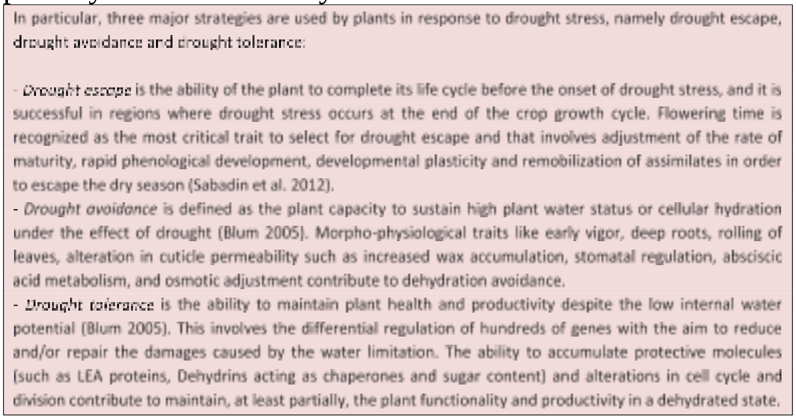
Genes encoding the cytosolic ascorbate peroxidase, glutathione per- oxidase and manganese superoxide dismutase are, for instance, induced under drought stress and responsible to regulate ROS homeostasis (Karpinski et al., 1997; Davletova et al., 2005; Wang et al., 2005; Miao et al., 2006). For the production of osmoprotectants, such as proline, tre- halose and betaine, the expression of genes involved in their biosynthe- sis, including 1-pyrroline-5-carboxylate synthase (P5CS) (Verbruggen et al., 1993), the trehalose-6-phosphate synthase (TPS1) (Yeo et al., 2000) and the betaine aldehyde dehydrogenase (BADH) are also regu- lated by ABA-dependent transcription factors (Zhang et al., 2011). To- gether with that, several chloroplast-to-nucleus retrograde signaling pathways are also activated to adapt chloroplast activities to physiolog- ical needs (for a review see Chan et al., 2016). The few genes described above, together with many others that we are not able to fully cover here since the stress scenarios are too broad, are currently at the center of scientific attention for the design of effective drought-adaptation strategies in crops.

2.2. Traits and precision phenotyping for drought adaptation

Genetic variation is found in crop species for various types of drought stress responses. These differences allow plant breeders to generate combinations of traits in elite genetic backgrounds, and develop cultivars with wider adaptability to various drought stress scenarios and stable yield under unfavorable environmental conditions. To assist with gene discovery, precision phenotyping protocols are based on multi-site experimental facilities located in important crop production areas and equipped with basic field facilities, including weather stations, access to soil analysis, and phenotyping tools suitable to monitor different traits such as early vigor, early maturity, photosynthetic activity or water status of plants. Imaging techniques are widely used to phenotype specific parts of the plant. Additional traits for precision phenotyping include canopy cover, leaf temperature, biomass production, together with root weight and length (for a review De Almeida Silva et al., 2012, Khan et al., 2016). Clearly, precision phenotyping needs high-throughput analytic capabilities and software, both still representing bottlenecks in high throughput phenomics. Nevertheless, phenotyping will be instrumental to evaluate the most promising combinations of morpho-physiological traits for future agro-climatic conditions.

2.3. Biotechnology and breeding

Once the most promising morpho-physiological traits for drought adaptation in specific agro-climatic scenarios have been identified and their modelling-based combinations proposed, genomics assisted breeding for drought adaptation can be initiated by using different strategies:



In particular, three major strategies are used by plants in response to drought stress, namely drought escape, drought avoidance and drought tolerance:

- *Drought escape* is the ability of the plant to complete its life cycle before the onset of drought stress, and it is successful in regions where drought stress occurs at the end of the crop growth cycle. Flowering time is recognized as the most critical trait to select for drought escape and that involves adjustment of the rate of maturity, rapid phenological development, developmental plasticity and remobilization of assimilates in order to escape the dry season (Sabadin et al. 2012).
- *Drought avoidance* is defined as the plant capacity to sustain high plant water status or cellular hydration under the effect of drought (Blum 2005). Morpho-physiological traits like early vigor, deep roots, rolling of leaves, alteration in cuticle permeability such as increased wax accumulation, stomatal regulation, abscisic acid metabolism, and osmotic adjustment contribute to dehydration avoidance.
- *Drought tolerance* is the ability to maintain plant health and productivity despite the low internal water potential (Blum 2005). This involves the differential regulation of hundreds of genes with the aim to reduce and/or repair the damages caused by the water limitation. The ability to accumulate protective molecules [such as LEA proteins, Dehydrins acting as chaperones and sugar content] and alterations in cell cycle and division contribute to maintain, at least partially, the plant functionality and productivity in a dehydrated state.

Textbox/Fig. 4. Plant adaptation to drought stress (Sabadin et al., 2012).

2.3.1. Marker assisted selection

In breeding applications, use of molecular markers is among the most powerful tools. They can be diagnostic (i.e. perfect markers of a specific allele within a specific gene sequence) or putative (e.g. markers associated with or flanking a QTL discovered via mapping in biparental crosses or in association panels). Diagnostic markers are used to select desired alleles in any parental or progeny line of a species under any crossing strategy. Alternatively, such markers can be used for transgenic manipulations (genetic modification, GM) within or across crop species. QTL markers from mapping studies are not perfectly linked to genes, but they are in linkage (‘nearby’) and are frequently difficult to transfer between crosses, unless there is substantial investment in crossing and mapping to ‘fine map’ the QTL to locate markers within a gene. The identification of QTLs for complex traits is further confounded by substantial genotype x environment interaction effects that occur for traits like heat and drought adaptation. However, new statistical methods enable modelling of QTL x environment effects and more robust detection
of useful genomic regions for selection (Boer et al., 2007).

Only few QTLs of large effect have been

documented for performance-related traits under heat or drought and no candidate genes have been shown to have large effects on performance or yield. In part, the low success rate for these stresses relates to the genetic and environmental complexity of drought adaptation.

2.3.2. Next generation sequencing technologies and breeding

With the advent of next-generation sequencing (NGS) technologies, genotyping is moving from amplicon-based low-throughput (LTP) to SNP-based high-throughput (HTP) systems (reviewed in Nepolean et al., 2018). The abundance and cost-effective assays make SNP a pre- ferred marker choice for genomic studies. High-density SNPs are needed for high resolution fingerprinting, genome-wide association mapping (GWAS) and genomic selection. Low to medium density SNPs are needed in genetic diversity analysis, QTL/trait mapping, marker-assisted selection (MAS), marker-assisted recurrent selection (MARS) and candidate gene-based selections.

NGS-based sequencing technologies were used to capture the SNPs at whole genome level. Now, third-generation sequencing technologies (Jiao and Schneeberger, 2017) have emerged capable of generating long-read sequences. Pacific Biosciences (PacBio) Single Molecule Real Time (SMRT) sequencing, Illuminas Tru-seq Synthetic Long-Read

technology and the Oxford Nanopore Technologies sequencing platform offer third-generation chemistries to capture SNPs. Whole-genome se- quencing also provides functional information on genes and SNPs. Genome-wide SNPs will be eventually used in identification of haplo- types and in genetic mapping.

2.3.3. Genome editing

Targeted genome editing is the latest approach to manipulate gene function. For plant genome manipulation, short palindromic repeats (CRISPR) and CRISPR-associated protein9 nuclease (Cas9) are used (Cong et al., 2013). The employment of truncated-gRNAs (tru-gRNAs) reduces the risk to generate off-target mutations (Osakabe et al., 2016). Through genome editing approaches, point mutation (deletion or in- sertion), gene knockouts, activation or repression of genes and epigenetic changes are possible (Kamburova et al., 2017). In maize upstream of the liguleless1 (LIG1) gene, male fertility genes (Ms26 and Ms45), and acetolactate synthase (ALS) genes (ALS1 and ALS2) have been successfully altered through targeted mutagenesis, precise gene editing, and site-specific gene insertion using Cas9 and guide RNA (Svitashev et al., 2015). A CRISPR/Cas9 binary vector set was devel- oped as a toolkit to perform multiplex genome editing in a variety of plant species including maize (Xing et al., 2014). Biolistic delivery of pre-assembled Cas9–gRNA ribonucleoproteins into embryo cells, and DNA- and selectable marker-free recovery with mutated alleles at high frequencies was demonstrated in maize (Svitashev et al., 2016). Genome editing is currently akin to MAS where one or few genes are being modified for a given trait. Since drought tolerance is a complex trait, many genes need to be targeted to achieve the desired level of tol- erance. Mutant lines can be created for various drought-responsive genes and those genes can be introgressed into a single genotype through pyramiding. Since pyramiding approaches are laborious and re- source intensive, up-grading or modification in the existing genome editing approaches is needed to alter several genes operating in various pathways in a genome at one go. Such an advanced approach will be useful to manipulate several target genes of individual and component traits to develop drought tolerant genotypes rapidly.

3. Employing the microbial hub

Arable soils provide a diverse range of beneficial microbes that crops can recruit, like mycorrhizal fungi, other rhizospheric symbionts and endophytes (van der Heijden et al., 2015; Estendorfer et al., 2017). Growing crop varieties with improved compatibility towards beneficial soil organisms can be a powerful way to manage soil health and a good strategy to enhance soil nutrient use efficiency (Ellouze et al., 2014; Rillig et al., 2016). Endophytes, nitrogen fixing bacteria and mycorrhizal fungi live symbiotically within plants and can promote growth, nutrient use efficiency, stress tolerance and pathogen resistance (Le Cocq et al. 2016). For instance, research has shown that arbuscular mycorrhiza (AM) can determine nutrient composition in plants (Ravnskov and Larsen, 2016) as well as increase plant tolerance against abiotic stress like heat (Cabral et al., 2016), drought (Zhou et al., 2015) and biotic stress caused by soil borne pathogens (Yu et al., 2012). In brief, a great body of evidence demonstrates that the microbiome can improve the nutrient status of the plant and the crop resilience to biotic and abiotic stresses (see also Section 5.4).

In addition, it has been shown that a plant attacked by pests can warn and thereby induce plant defense in the neighboring plant through the AM fungal mycelium connecting the plants in the soil (Cabral et al., 2018). However, farmers influence the occurrence of soil microbes, for instance, the diversity of root-associated fungi seems to change with increasing amount of organic fertilization and part of this change is an increase in AM fungal root colonization (Yu et al., 2013). This is in agreement with results of Kahiluoto et al. (2009), who found that AM symbiosis stimulates plant nutrient uptake in low-input sys- tems with organic fertilization. Such ecosystem services play an inte- grated role in plant nutrient uptake and growth, and are essential for economic and sustainable crop production (Gianinazzi et al., 2010; Smith and Smith, 2011). Next generation cropping systems must better incorporate the microbiome aspect of agriculture (Gopal and Gupta, 2016). With this ‘holobiont’ view of plants and microbiome-extended genotypes (Vandenkoornhuyse et al., 2015), a huge potential exists to improve integrated cropping by microbial treatment (Fig. 5) to enhance productivity at lowered chemical inputs, resulting in significant envi- ronmental and financial benefits (Murphy et al., 2017).

4.1. Triggering the Holobiont

Since the importance of microorganisms in the lives of all higher or- ganisms has been recognized, their ubiquity has led to the concept of the hologenome as a genetic unit representing the combined genomes of a host and associated microorganisms (Moran and Sloan, 2015).

Crop fields can be regarded as holobionts according to this theory. The microbiome of plants is closely linked to soil microbial characteristics and a large proportion is recruited directly from the soil (Bonfante and Genre, 2010; Xu et al., 2012). Pot and rhizobox studies have shown how important microbes and AMF for nutrient acquisition may be (Ravnskov and Larsen, 2016), and metatranscriptomic analyses have provided first insights in the required set of players in the rhizosphere (Xu et al., 2012), while laboratory and field experiments have proven the active contribution of plants in the recruitment of root colonizing microbes. Since gene expression of rhizoplane colonizing bacteria is under the control of bacterial signals, a central role for communication via quorum sensing compounds has been established. As part of this sig- naling pathway, plants are known to emit a variety of organic acids, exsudates, from their roots. Metabolic profiling showed that cereal root exudates were modulated not only by fungal strains application, but even by fungal species biodiversity (Lucini et al., 2019). Data from these studies now have to be translated into practice to improve field management, so that seed inoculations can be tried to initiate so far lacking processes in the holobiont. In such a context, novel crop varie- ties could be selected in relation to their genetic variability and symbi- otic interactions with endophytes (Hohmann and Messmer, 2017). However, managing microbial inocula for yield improvement is a major challenge to farmers and inoculum suppliers, because the microbiome diversity of crops is immense while their function and mode of action has not been exhaustively characterized and several in- ocula that were successful in controlled conditions failed during field application due to unforeseen difficulties (Murphy et al., 2015; Yang et al., 2017).

4.2. Microbiome services for sustainable agriculture

Anyway, the use of plant-associated bacteria and microbial products has the potential to change the way we grow crops, with a bright per- spective of moving to a more sustainable, healthy and efficient agricul- ture. Just as recent advances in human microbiome research are revolutionizing medicine, applying new knowledge on the phytobiome to agricultural management practices could release our crops from a huge number of agro-chemicals, one of the pillars in which the green revolution of the 60s´ was sustained. Novel approaches using microbial products are emerging to improve plant protection against biotic or abi- otic stress and face problems derived from climate change like water scarcity and desertification (Fig. 5). The challenge is to optimize microbiome services in agroecosystems. Nowadays, farmers have a wide range of tools at hand to manipulate the microbiome of agricul- tural species for increased productivity and health or to confer specific organoleptic traits to their crops. The first techniques involve direct ap- plication of beneficial microorganisms. Plant growth promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF) or microor- ganisms for biological control in the field are commercially available in many countries since the 1950s. In fact, the current biofertilizer market represents about 5% of the total chemical fertilizers market (Timmusk et al., 2017). Bio-organic fertilizers containing functional microbes and specific organic substrates have shown to favorably modify rhizosphere microbial communities resulting in improved quality and health in apple and watermelon (Wang et al., 2016; Zhao et al., 2018). Recently, new promising and complex inoculants involving microbial consortia or even microbial communities have been developed with en- couraging results. A three component Azospirillum-Pseudomonas-Glomus consortium successfully promoted growth of maize (Couillerot et al., 2013), and inoculation with bacterial communities conferred dis- ease resistance in Nicotiana attenuata, revealing that a core consortium of five bacteria was essential for disease reduction (Santhanam et al., 2015). Transfer of soil microbiome alleviated drought stress in Arabidopsis thaliana (Zolla et al., 2013), and a core microbiome com- posed of Burkholderia, Phormidium, Bacillus, Aminobacter, Acidiphilum among others was identified as key player in alleviating the abiotic stress. In another study, foliar microbiome transplant resulted in disease resistance in Phyllostegia

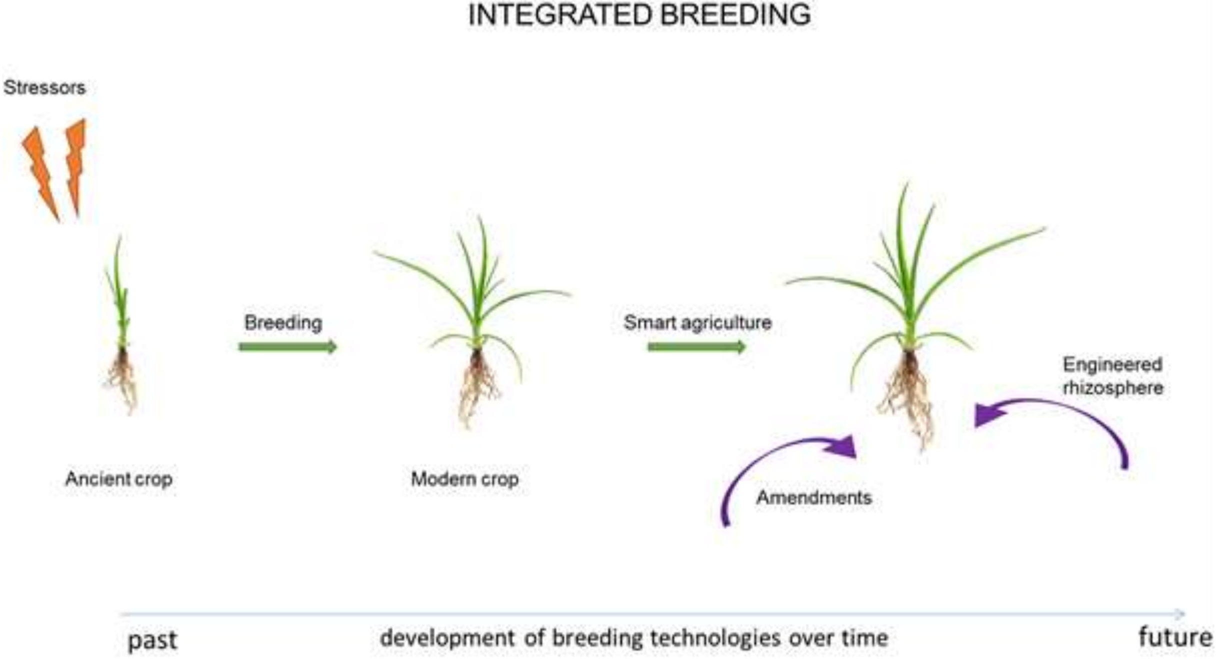


Fig. 5. Integrated techniques for novel crop breeding. While today's crops are selected for yield and pathogen resistance, modern crops will be designed for lower water consumption and other desired traits. Future crop design should be open for precise cropping approaches, engineered rhizospheres and accept optimized amendments for cropping by soils.

kaalaensis (Zahn and Amend, 2017). The use of lytic phages has been shown to reduce plant disease in potato crops (Czajkowski et al., 2017). This virus-based technique could represent a direct and precise tool for future microbiome manipulation.

Not only beneficial microorganisms can be applied but also microbial products. Indeed, the cross talk between microbes and plants occurring in the rhizosphere has already been exploited with positive results. Some studies using microbial signaling molecules such as N-Acyl L-Homoserine lactones (HSLs) have shown that application of these molecules to rhizospheres protects the plant against pathogens (Hartmann et al., 2014; Hernández-Reyes et al., 2014) and that plants can be primed by bacteria producing specific AHLs like Sinorhizobium meliloti. The same approach can be applied in the opposite direction for microbiome manipulation. Recently, it became clear that plants are able to select their root microbiome by changing their exudation pattern, in a programmed manner, for the benefit of the host in a given ecosystem (Hu et al., 2018; Zhalnina et al., 2018). These results open the door to new applications involving novel biostimulants for the improvement of plant fitness through plant microbiome manipulation.

Another way to manipulate root and soil microbiomes is through specific cropping practices. Hartman and coworkers showed recently that soil and plant microbiomes could be tuned by cropping practice (Hartman et al., 2018). In winter wheat, influential soil bacterial communities were primarily structured by tillage, whereas soil fungal communities responded mainly to management type with additional effects by tillage. In the rhizosphere, management type was also the driver for bacteria but not for fungi, which were more determined by tillage intensity. A holistic analysis including above- and belowground traits should be used for the evaluation of crops. Root biomass correlates with above-ground biomass and yield (Chmelíková et al., 2015).

The open question is if priming can be exploited in the frame of a sustainable agriculture as realistic tool to increase the resilience of both traditional and modern crops under a changing environment. Or, more widely, if microbial services can have a key role in agroecology, resulting in lowering the impacts of agriculture at the farm and land-scape scales.

Despite these recent advances, the development of microbiota management practices still requires much deeper understanding of agricultural microbiomes. Microbial populations introduced to farm- lands often decline rapidly (Streeter, 1994). Moreover, unexpected deleterious effects on ecosystem functions have not been well studied as yet. Thus, interdisciplinary research strategies involving the manipulation of microbiome assemblies and informatics pipelines for the identification of core microbiomes are required to optimize microbiome functions in agroecosystems (Toju et al., 2018).

It is noteworthy the fact that the effective role of microbiota exploitation in agricultural systems is now the object of robust debate. In many crops beneficial microbiota has been convincingly shown to increase yield, but cereal responsiveness to AMF and soil microbiota has not been fully elucidated. The debate is therefore particularly focused on cereals, mostly wheat, a major global crop. Criticisms have been raised by Ryan and Graham (2018) “if there is sufficient evidence to recommend farmers consider impact on AMF when making management decisions and to suggest high-priority areas for future research”. After reviewing the last 16 years literature focusing on cereal field experiments that manipulate indigenous AMF and report crop yield the authors concluded that “management of AMF by farmers will not be warranted until benefits are demonstrated at the field scale under prescribed agronomic management”. On the contrary, the meta-analysis from Pellegrino et al. (2015) carried out taking into account wheat field trials worldwide conducted, showed that AMF field inoculation increased wheat grain yield and harvest index. Also, varieties of wheat benefit differently from their symbiosis with arbuscular mycorrhizal fungi (AMF), e.g. under drought stress (Zhou et al., 2015).

Rillig et al. (2019) reply that yield is a crucial component for farmers and consumers in the short term, but it is necessary to take into account even long-term benefits for sustainability and yield stability of agroecosystems. Thirkell et al. (2017) hypothesize that the greatest benefit of high AMF colonisation in crop plants is non-nutritional, via the effects on soil structure and function, and on plant defences.

There is general agreement on the fact that the studies should now be scaled up to field, landscape or ecosystem levels to better understand the complex interconnections among crop and microbial partners. Moreover, Ryan et al. (2019) underpin that the massive introduction of microbial service in cereal cultivation must be preceded by a strong systems agronomy approach overlaying all research.

4. Breaking the rules

In today's agriculture, several dogmata could be critically inspected to approach better productivity and enhanced environmental friendli- ness at the same time. One of the strongest paradigms is the use of pure inbred varieties in monocultures. These cropping systems have been postulated to produce higher yield and to contribute towards fight against hunger in a global perspective. Conversely, it has been shown that mixtures of varieties adjusted to the conditions of the pro- duction site can lead to yield stability over a range of environmental conditions and sustained higher productivity than monocultures (Mundt, 2002). These effects were attributed to crops maintaining health-promoting soil microbial communities, enhancing resistance of the stand against disturbance by pests, and eventually also against abi- otic stressors (Kiær et al., 2009). Cultivar mixtures seem to represent a viable strategy to increase diversity in agroecosystems, promoting in- creased yield and yield stability, with minimal environmental impact (MEA, 2005; Reiss and Drinkwater, 2018). Higher yields of good quality will certainly compensate for varietal purity in a world facing famine. Hence it is necessary to thoroughly investigate options for mixed cropping and provide valid recommendations for the implementation of such cropping systems.

Since monoculture also leads to low microbial diversity in soil as compared to soil with crop rotation (Ferrari et al., 2015), traditional monoculture systems can be replaced by efficient crop rotation to im- plement high microbial diversity beneficial for crop production. Simi- larly, mixed row cropping and intercropping can increase microbial diversity, and high soil microbial diversity is positively correlated with crop yield (Duchene et al., 2017). The influence of quantity and quality of organic fertilization on inter-plant nutrient exchange via the AM hy- phal network seems to be high for both, monoculture or mixed cropping (Hohmann and Messmer, 2017).

Reduction in beneficial insect fauna viz. pollinators, predators and detritivores is another key problem due to monoculture systems (Zhang et al., 2007). Simultaneously growing wind- and insect polli- nated crops at the same site will provide feed for bees or other pollina- tors and lead to reproductive assurance (Friedman and Barrett, 2009). It will also improve habitats in non-productive areas such as field margins to support insects (Kovacs-Hostyanszki et al., 2017).

To protect surface waters, buffer zones are strongly recommended alongside field, and hedgerows and buffer zones are key contributors in reducing pesticide drift in agricultural lands (Lazzaro et al., 2008). Other benefits include wildlife habitat creation (Heath et al., 2017), en- hanced pollinators' activity and biological control of insect-pest by con- servation of natural enemies (Morandin et al., 2016). Establishment costs are a major disincentive to the adoption of hedgerow intercropping (Nelson et al., 1996). Crop yields can be reduced due to competition between the crops being grown in the system. Additionally, weed management in hedgerows or buffer zones can be a challenging task resulting in increased competition with the main crop (Rao et al., 1991). Intercrops may also harbor various kinds of insect-pests in addi- tion to the beneficial insects (Pannell, 1999).

5.1. Shaping the agro-environment

In order to recognize and eliminate weaknesses in a given system, the entire process must first be analyzed and examined. Digitalization is therefore also a big step forward in agriculture management. Elabo- rate maps on soil, environment and production related issues are the starting point for increased sustainable production. To date, data ob- tained from the evaluation of satellite images, aerial photography and multi-spectral sensor techniques can provide the farmer with valuable information about the optimal management of his land. Mobile proxi- mal sensors and drones characterized by precision, user-friendliness and minimal cost overcome the limitations associated with current in- strumentation of satellite- or aircraft-based sensing systems for map- ping crop condition and soil properties (Fig. 6). They differentiate

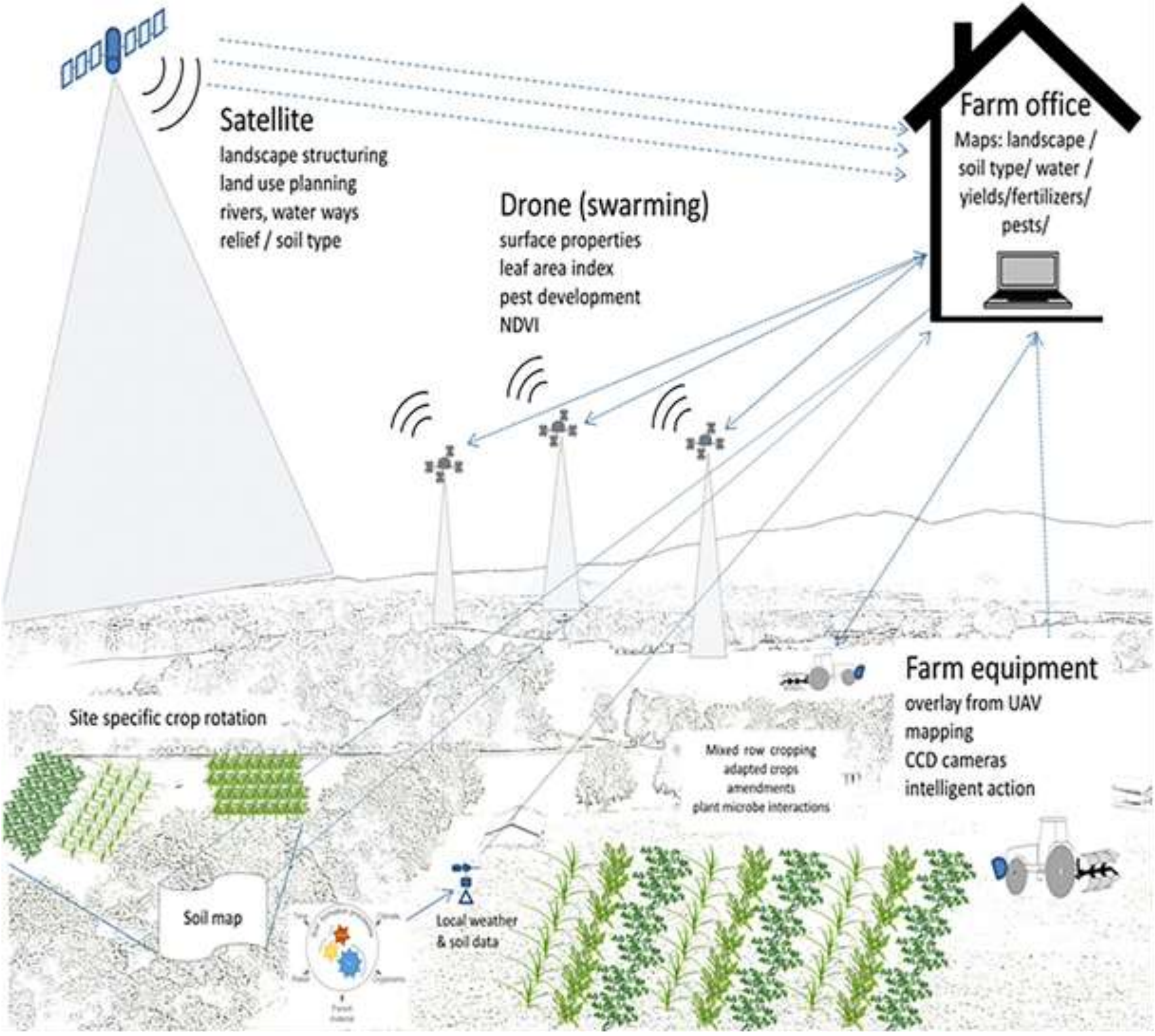


Fig. 6. Integrating remote sensing techniques for more efficient soil and crop management.

In order to reach optimum performance in future agriculture, it will be necessary to utilize the advantages of mapping and precise farming. Satellites can help designing optimized field size, shape and borders. They can also provide remote information on plant performance in rotation, and water availability connected to soil types and weather data. These maps can be translated into precise management plans which are supervised by proximal sensors in drones, and farm machinery. For short term decisions on seeding density, fertilizer management or phytosanitary measures, swarming drones can supply real time data. GPS driven farm machines will then seed appropriately, apply fertilizers accurately, and spray compounds for plant protection (organic or integrated) with precision accuracy. Utilizing the potentially available data will make the ecological footprint smaller, preserve water quantity and quality, and lead to sustainable biomass production for food, feed and byproducts.

between water stress and nutrient deficiency, a key element to apply variable-rate inputs in an integrated way, with multispectral sensors. Overall, they help to implement smart and conservative farm manage- ment strategies for future agri-environmental schemes.

On such a background, farms can be optimized by re-structuring field sites, inserting hedges, buffer strips, tree lines and fallow for biodiversity protection as well as by determining the need for irrigation or modifying tilling plans, according to local climate and soil condition. Im- pacts on soil quality and sustainability have to be monitored as changes in soil properties such as soil organic carbon, clay content, structure, pH, cation exchange capacity and degradative processes such as compac- tion, erosion, nutrient depletion and salinization affect soil biodiversity, soil organism activities (micro-, meso- and macrofauna), weed dynamics and crop yields. Soil/crop management, local weather, parent sub- strate and terrain are all further factors that need to be monitored in order to sustain soil and ecosystem health and functionality. Next, it will be necessary to translate the available knowledge into site-specific farming techniques that will promote resilient soil life and to stimulate cycling of nutrients. It is known from precision farming ap- proaches that high organic matter zones have greater water holding ca- pacity and nitrogen mineralization potential, and thus, need reduced water and nitrogen inputs relative to low organic matter zones.

Contour farming, shortening slopes and reduced tillage have all been proven to be solutions for erosion problems and water management in hilly landscapes (Reents et al., 2008; Auerswald et al., 2009). If exact spatial and temporal irrigation, composting and fertilization needs of each management zone are determined, mixed cropping fields will produce highest yields.

5.2. Amendments enhance resilience

It has been postulated that the largest part of fertilizing and enhanc- ing water holding capacity of soils can be reached by organic amend- ments (Reichel et al., 2018, Schröder et al., 2017). Among them compost, animal manure, tree litter and green manure and cover crop residues providing large amounts of fibers and carbon enhance the quality of fields and maintain physical and chemical characteristics at high status. Perhaps one of the greatest opportunities to further develop sustainable agriculture is brought about by the challenge of effectively incorporating organic amendment schemes and manure management into cropping systems at minimum environmental risks (Schepers et al., 2000; Moshia et al., 2014). Manure application with precision farming techniques has been demonstrated and could therefore evolve into being part of good agricultural practices, in both integrated and organic farms. Organic amendments improve the water retention capacity and thus enhance drought tolerance of the canopy. In spring and after harvest, organic amendments can also prevent that soil particles are eroded by intense rain or wind (Magdoff and Weil, 2004). Of course, precise manure management needs to find a compromise between eco- nomic and environmental issues that will aid soil fertility improvement on poor soils and consequently enhance crop yield across the whole management zone (Moshia et al., 2014).

New methodologies to elaborate compost, the use of agricultural

and farming organic waste, as well as the introduction of waste from agroindustry, the quality control procedures and the application guide- lines have made a new investment opportunity for compost and organic amendments products. It would be tempting to use municipal solid waste (MSW) for composting and contribute to the “end-of-waste” European policy (Saveyn and Eder, 2014). However, the quality of the composts depends on the source and proportion of waste, as well as on the quality of the composting plants facility and the maturation pro- cess (Hargreaves et al., 2008), and hence compost elaboration, quality and application must follow national and international guidelines. Since it has been recognized that some amendments used to create con- ditions favorable to crops may negatively affect the beneficial microbial associates of plants that are adapted to soil conditions suboptimal for production (Ellouze et al., 2014), it is important to study the effect of amendments and suppressive composts in laboratory systems before applying them to the field. Sewage sludge application can also increase soil nutrients and organic matter content, improve soil structure and re- duce costs, but there are some limiting factors yet to be studied. Some risks associated to the compost from MSW and sewage sludge in the past were the increase of salinity and the presence of heavy metals and organic pollutants, pathogenic microorganisms and, in some cases, the presence of micro and nano plastics (Alveranga et al., 2015). This can, from a legal point of view, trigger a situation, where such com- posts remain considered as waste and their use in agricultural and horticultural land is severely restricted (Farrell and Jones, 2009). With reusing and recycling resources, in which compost (‘waste’) -output from one metabolic urban conversion equals input for another (Wielemaker et al., 2016), the nutrient movement from products of agricultural land to cities can be balanced with the reverse movement and reuse of waste nutrients in form of compost to agricultural land. In this context, the CO2 footprint of all actions that include the elaboration, transportation and application must be determined. If balanced, this al- ternative is in agreement with novel trends based on circular economy to enhance local resources.

As already discussed above, a major problem in crop production is
the timely availability of water. Several countries already nowadays en- counter severe water shortage, if not droughts, during the cultivation period. New crop variates with better water use efficiency as discussed above and with tailor-made organic amendments can mitigate prob- lems of water supply. Fresh organic matter and manure have a stronger effect on microbially-mediated soil structuration than stable organic matter, while the effect of the latter is long-lasting particularly when large amounts are applied (Geisseler and Scow, 2014). Organic amendments favor fungal and microbial proliferation and adsorb nutrients and retain water. This increases the soil nutrient pool, soil moisture levels and soil health, which further supports the growth and quality of crops (Ellouze et al., 2014).

The recent introduction of biochar and biochar-compost products adds a new option to improve soil fertility, remediate degraded land and mitigate greenhouse gas emission from farm land. The conversion and valorization of organic waste into a soil amendment can be a suit- able solution to maintain an appropriate level of soil organic matter and the nutrient cycle, but research is needed on composition and elab- oration of these amendments, application doses, and long-term effects (Agegnehu et al., 2017). It is evident that biochar influences physico- chemical and biological properties of soils, providing habitats for bene- ficial soil bacteria and mycorrhiza. This alone can enhance nitrification, reduce GHG emissions (Atkinson et al., 2010; O'Neill et al., 2010), by that resulting in reduced fertilizer application and increased water retention. While biochar-compost mixtures have the potential to re- plenish deficiency of nutrients in soils of medium fertility, crop produc- tivity can also suffer. Properties of biochar must hence be scrutinized in short and long term trials to unravel the mode of action and to evaluate biochar versus compost from same feedstock as a part of future line of soil improvement.

5.3. Increase resilience with crop rotation strategies

Biological diversity is the foundation for the maintenance of ecosys- tems. Consequently, it is thought that anthropogenic activities reducing the diversity in ecosystems threaten their performance (Wagg et al., 2014). A combination of methods is required, integrating diverse rota- tions, including diverse leguminous and non-leguminous crops, break crops and cover crops and highly competitive crops (e.g. bioenergy crops), cultural methods to increase the competitiveness of crops (Bàrberi, 2002). Improved crop rotation planning has to take into ac- count regionally different problematic winter and spring annuals and perennial weeds at the same time (Bachinger and Zander, 2007). In the past, rotational schemes with 4 or 5 greens and cereals have proven to be most effective in sustainable farming, and nutrient efficiency. They are also optimal with view to market flexibility. For example, typically a green (potato/canola/alfalfa) should be followed by a grain (winter bar- ley or rye), alternated to yet another winter grain. As fourth fruit, an early summer green (sunflower, pulses, silage maize) can be sown, be- fore a summer cereal (barley or wheat) will complete the scheme. De- pending on soil quality and market situation, turnip, potato or beets might be added. Several software tools for rotation planning are on the market, among them ROTOR (Bachinger and Zander, 2007), ROTAT (Dogliotti et al., 2003) or others. To keep mineral fertilizer at minimum, compost, green manure and amendments pelleted from chicken manure, spent mushroom substrate and biogas residues can be used as supplementary fertilizer, replacing chemicals. Under such conditions, an increase in carbon and minimization of N losses can be expected.

An important player in future agriculture is the use of meta-data and prediction. Process-driven models are able to simulate the growth, development and yield levels and quality of agricultural crop and grass- land as a function of weather, soil management and crop genetics (Brisson et al., 2003; Jones et al., 2003; Nendel et al., 2011). Thus, such models are a useful tool to determine production performance of crop, crop rotations and perennial grasslands under climate, weather and soil conditions beyond what is feasible to determine experimentally. Notably, process-driven models have been used extensively to determine crop production potential and different climate change scenarios (White et al., 2011) as well as to determinate crop yield sensitivity, spa- tial soil variability (Persson et al., 2015) and to inter- and intra-annual weather variability. Moreover, crop simulation models can be used to set breeding goals and to determine the performance of hypothetical cultivars under climate change (Semenov and Halford, 2009) and other foreseen or aimed future conditions such as changed soil conditions. It is of great importance that simulation studies are closely linked to experimental data against which crop and grassland parameters are calibrated, and their accuracy is evaluated before simulations of hypo- thetical or aimed crops and cropping systems. In total, a smart combina- tion of experimental and simulation studies could increase the knowledge of the effects of spatial climate, weather and soil variability as well as temporal climate and weather variability on crop and grass- land yield levels and stability. Such knowledge is, in turn, essential for a successful implementation of novel management methods across large regions with varying climate and soil conditions.

5.4. Novel approaches to sustainable pest management

Control of pests is a key factor to crop production. Failure to control pests already in simple cropping systems will lead to yield reduction and crop failure (Fig. 7). However, reliance on heavy pesticide usage is more and more seen as critical. Global concerns about pesticide residues in food chain, adverse effect on soil flora and fauna as well as their harm- ful effect on the environment have drawn the attention of researchers and practitioners to find novel ecologically sound practices insect and weed management practices (Pujari et al., 2013).

Growth and physiology of weeds and crops can only be understood with respect to their interactions in a changing climate scenario. Nota- bly, too narrow a reliance on herbicides has resulted on the one hand in a few species becoming endangered (e.g. in Europe: Adonis aestivalis, Agrostemna githago), while other species expanded and weed control became difficult because of their resilience (in Germany e.g.: Alopecurus myosuroides, Equisetum arvense, Polygonum persicaria). Novel integrated pest management (IPM) strategies which combine remote sensing with drones, decision making for weed control and optimization and targeted changes of active substances in chemical control as well as management practices such as soil tillage, planting time and density, fertilization, irrigation and crop rotations allelopathic potentials could be beneficial to control these types of pest problems. The use of chemi- cal pest control methods should be based on economic pest population

Fig. 7. Failure to control weeds in maize (2016, upper Bavaria, Germany) leads to rapid overtopping of the crop in early summer and to severe yield reduction, or even complete loss at harvest (photo by Georg Gerl).

thresholds and critical periods when pests cause damage to crop spe- cies. This is essential, since failure to control weeds already in simple cropping systems will lead to yield reduction and crop failure (Fig. 7). Future agriculture needs to select among the broad spectrum of crop protection methods which involves the utilization of ecologically sound practices, thus emphasising on the basic principle of integrated pest management (IPM) and being supportive to the environment (Amadou Binta and Barbier, 2015).

To further optimize herbicide use to minimum effective rates by adapting to the weed species, growth stages as well as to the climatic conditions is important for sustainable weed control to further reduce costs and environmental hazards. In order to overcome low soil persis- tence or narrow effect spectrum, mixtures of different active ingredients have to be adapted to the weed control strategies. This will broaden the effect spectrums of mix partners as well to prolong the duration of ef- fects. To further increase the efficacy, additives and/or adjuvants of nat- ural origin can be included in the mixture.

Technical solutions for site-specific weed control are on the way, using different approaches of remote and proximal sensing. With the in- creasing speed of computing and imaging, it will soon be possible to use spot-spraying with varying herbicides to ensure lowest possible pesti- cide load on soil and non-target plants (Esau et al., 2017).

But whenever possible, preventive methods should be applied be- fore or after planting to reduce the number of diaspores, to delay the timing of weed emergence, to prevent the introduction of new weed seeds into the field as well as to improve crop performance against weeds. Soil tillage, planting date, density of crop plants per unit growing area, amount and type of irrigation and fertilization are important fac- tors affecting the interactions between crops and weeds in the short run. Crop species having allelopathic potentials should preferably be chosen in rotation or intercropping systems as well as cover crops to ob- tain a sustainable weed control (Jabran et al., 2015; Farooq et al., 2011). Allelopathy maybe a challenging topic for future weed control strate- gies. These natural suppressive substances can be used as living or dead mulches in crop rotation systems, as biorational herbicide extracts for weed control.

With view to organic farming, it might be worth to implement dis- ease and pest control systems into spot spraying applications, taking biocontrol agents, resistant varieties, intercropping and mechanical methods into account. Such an overlapping weed control strategy would embrace the best available technologies of all production sys- tems and protect our resources at the smallest possible ecological footprint.

In this context, the capacity of microbial inocula and mycorrhiza to reduce plant disease has also been proven (Ellouze et al., 2014; Rankl et al., 2016). Also, more studies have shown that high natural occur- rence of AM fungi in soil was correlated with lower incidence of root disease (Yu et al., 2012; Xu et al., 2012).

As a complement to a more efficient herbicide use described above mechanical progress must not be neglected. Already now, video image analysis methods are available to exactly determine positions of crop plants in a canopy and then mechanically remove weeds from the inter- mediate rows and, most importantly, between the plants in a row. As long as the foliage of plants can clearly be distinguished from each other, and for crops planted at regular intervals and row spacing, such a method will remove weeds even without chemical inputs.

For insect pest management in organic farming, use of biorational in- secticides, hedgerow, intercropping, crop rotation, growing of resistant varieties, tillage, trap crops, conservation, augmentation and periodic release of natural enemies has been recommended (Lotter, 2003; Zehnder et al., 2007; Willer et al., 2008). In this context, the use of plant extracts as biorational insecticides is gaining popularity. These plant based biorational insecticides can be defined as any type of bio- chemicals extracted or derived from plants which is active against pest populations, but relatively harmless to non target organisms and therefore, non-disruptive bio control agents (Howell and Hazzard, 2014). Their use dates back at least two millennia in ancient China, Egypt, Greece, and India. Depending on the mode of action, these biorational insecticides can be categorized into: toxicants, repellents, feeding deterrents/antifeedants, growth regulators, chemosterilants, at- tractants and synergists. For example: pyrethrins, rotenone, ryania and nicotine are the most common commercial botanicals owing to their toxic nature against a variety of insect-pests (Pavela, 2016). Citronella oil, eucalyptus oil and lemon oil are strong repellents, while chinaberry and Melia azadirach extracts are strong deterrents (Chandler et al., 2011; Villaverde et al., 2014). Similarly, Lindera erythrocarpa and Soli- dago serotina are natural insect growth regulators (Lee et al., 2015). Andrographis lineata, A. paniculata, essential oils of garlic, citronella, eu- calyptus, lemon and wintergreen oil are chemosterilants (Renugadevi et al., 2013). Onion and Araujia serisofera are used as attractants in baits. Dillapiol, sesame oil, citronella oil and pongamia oil are natural synergists for various commercial insecticides (Pinheiro et al., 2013). These products would enable to develop and impellent environmentally friendly insect pest control strategies that will meet the expectation of consumers and society. Meanwhile, these new control tools will lead to reduction in use of synthetic insecticides, that will help to restore bio- diversity in arable crop fields where extensive pesticides application caused dramatic reductions in many plant and insect species. Some plant-based products such as neem extracts have shown promising re- sults when tested against different insect herbivore in the field.

New approaches are also on the way to improve the enantioselectivity of processes that determine the fate of pesticides in agricultural soils, in- cluding assessment of the influence of certain agronomic practices on such enantioselective behavior. An innovative proposal of these studies is the design of active-enantiomer slow release formulations using clay or organic amendments as a support. These formulations would permit reduced pesticide application rates and minimize the agrochemical losses by transport processes, improving its efficacy against the target pest, in- crease their efficacy and reduce their environmental impact (Gámiz et al., 2016; López-Cabeza et al. 2016, 2017).

Crop resilience to biotic stresses can even be improved by exploiting plant priming phenomena. Priming is an adaptive strategy triggered by different stimuli that enhance the defensive capacity of plants against environmental stresses. A primed plant activates faster and/or stronger defense mechanisms after the onset of the stress. At the same time, the primed state is not costly for the plant, in terms of either plant growth or yield. This intriguing mechanism is therefore a form of immunological plant memory that can be potentially exploited to increase crop resilience. Priming is now considered an intrinsic part of induced resistance and can be divided into a “priming phase”, a “post-challenged primed state” and a “transgenerational primed state” (Balmer et al., 2015). In the priming phase, the period between the stimulus perception and the occurrence of a stress, several biological changes take place in the plant to prepare an enhanced response. These physiological, molecular and even epigenetic changes can be either transient or permanent, inherited and either specific or generically induced by several different stimuli (Pastor et al., 2014).

Previous studies have demonstrated how both plant-growth pro- moting fungi and molecules can trigger priming, inducing low cost changes in the plant that enhance responsiveness upon challenge. Among molecules, the non-protein amino acid DL-3-aminobutyric acid (BABA) is a well-known priming inducer that has been even proposed as novel plant (priming) hormone (Baccelli and Mauch-Mani, 2017). Among commercially available products, some synthetic fungicides have been shown to have a dual mode of action, i.e. direct antifungal activity as well as activating a (low) level of induced resistance. Benzothiadiazole or BTH, commercially available as Bion® is perhaps the best known synthetic elicitor. Some plant extracts have been shown to possess activity against a range of pathogens on many crops, though it is not clear how much of this control is due to induced resistance or to a direct antimicrobial action (Lyon, 2007). Priming fits in the ecological context of induced resistance but it is not exactly coincident with it, being an adaptive plant's solution to the trade-off dilemma between disease protection and costs involved in direct defense activation (Mauch-Mani et al., 2017). In other words, a priming treatment puts a plant into a state of increased alertness with no or only minimal gene induction (Slaughter et al., 2012). Basically, these methods encourage to design a wide range of alternate ways to minimize reliance on synthetic insecticides and fungicides. Modern techniques can contribute to food security if properly utilized in a compatible manner and could make organic ecosystems unattractive to pest species.

In conclusion integrated pest management strategies are extremely beneficial for sustainable crop production, in which preventive methods are primarily applied and combinations of different post emergence treatments are included. Allelopathic compounds are challenging tools for future weed control, so special attention should be given to investigations with these substances. The use of herbicides should be minimized by optimizing application rates and combining with other weed control methods as well as applying them by precise technologies. Simultaneously, the reduction of herbicides influences insect biodiversity (ecosystem services), e.g. parasitoids providing biological pest control. A systematic approach is now needed to implement beneficial microbes into integrated crop protection of mixed cropping systems to reduce the plant-pest pressure (Fig. 7).

5. Bridging the gaps

When smart agricultural management on highly productive sites provides options to sequester nutrients and to convert crop residues into raw material for biogas and digestate or composting, it contributes to smaller carbon footprints. Following the initiative of the 4 per 1000, carbon farming should include cover crops, rotating crop, reducing tillage, compost or manure applications to fields (Chabbi et al., 2017; Rumpel et al., 2018). Site-specific soil and land use data will support decision makers to obtain an overview of regional soil quality, and which areas should be prioritized for investment to improve soil carbon stocks. Furthermore, precise strip intercropping will save water and sequester carbon (Altieri et al., 2017, Bybee-Finley and Ryan, 2018).

Precision can also be added to harvest and post-harvest procedures. During harvest, a significant proportion of the valuable crop remains on fields due to improper adjustment of the harvesters. This is a well-known problem of potato and cereal production (Humburg, 2016). By more precisely adjusting reels, cutting bars and conveyors this can be prevented, and volunteer crops (that need to be controlled by herbicides) can eventually be minimized. Of course, further groundbreaking research is needed, principally aimed at developing management recommendations for elaborate high yielding cropping systems by improving microbial diversity of soils, and to maximize the positive interactions between plants and their root systems and other organisms in the field, in order to reduce chemical inputs by improving ecosystem services.

The benefits and socio-economic implications of adopting sustainable practices in face of ecosystem services and climate change mitigation in agricultural production systems can easily be communicated to the public. Adding value to existing agricultural and food value chains has a strong potential to create jobs and income opportunities. Impacts of efforts made to sustain such natural resources continuity and reduce poverty could soon become visible as well as the impacts of crop man- agement and microbiota functionality on key ecosystem services such as carbon sequestration, nutrient cycling, pollution prevention, irriga- tion and climate change mitigation in an agricultural production system. Moreover, adding value to existing agricultural and food value chains has a strong potential to create jobs and income opportunities, and thus counteract poverty and low attractivity of rural areas. This is all in accordance with the above mentioned SDGs and the 2030 Agenda for Sustainable Development. It is now timely to change current para- digms to keep the agricultural productivity at its level, to increase resil- ience against climate change and pests, in order to avoid an increasing decay of our production systems, and our soils.

For a new momentum in agriculture, we must be open to innova- tions and cross borders, convince industry to invest in novel technologies, as well as to rethinking and education regarding sustainable agriculture. Diversification at the cropping systems level with new vari- eties is ever so important. Relying less on external nutrient supply while conserving water resources is an essential requirement for farmers to increase global food production on a sustainable basis.

While large scale farms are the core of food and fodder production, the role of smallholder farmers in exploring new ways to increase agricultural productivity and sustain soils will be equally important. Farmers are at the center of any process of change involving natural resources and for this reason they need to be encouraged through appro- priate incentives and guided governance practices, to minimize the negative impact agriculture can have on the environment (Bruinsma, 2017). While practical solutions are developing, science based recommendations for water (re)use, crop rotations, breeding and harvest/ postharvest strategies leading to environmentally sound and pollinator friendly production and better life in rural areas have to be communi- cated. In this context, it will be ever so important to bridge the gap be- tween scientific findings and tools usable for advisors and farmers, to increase the understandability of results and to translate science into ac- tion plans.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.04.212.

Acknowledgements

The authors thank the FACCE Surplus JPI and COST Actions Wa- ter2020 (ESSEM 1202) and NEREUS (FA 1403) for valuable information and the opportunity to meet and discuss the issues related to this topic in stimulating environments and perfectly hosted workshops.

References

Agegnehu, G., Srivastava, A.K., Bird, M.I., 2017. The role of biochar and biochar-compost in improving soil quality and crop performance: a review. Appl. Soil Ecol. 119, 156–170.

Akhoundi, A., Nazif, S., 2018. Sustainability assessment of wastewater reuse alternatives using the evidential reasoning approach. J. Clean. Prod. 195, 1350–1376.

Alberola, C., Lichtfouse, E., Navarrete, M., Debaeke, P., Souchère, V., 2008. Agronomy for sustainable development. Ital. J. Agron. 3, 77–78.

Alcalde-Sanz, L., Gawlik, B.M., 2017. Minimum Quality Requirements for Water Reuse in Agricultural Irrigation and Aquifer Recharge - Towards a Legal Instrument on Water Reuse at EU Level, EUR 28962 EN, Publications Office of the European. Union, Luxembourg.

Altieri, M.A., Nicholls, C.I., Henao, A., Lana, M.A., 2017. Agroecology and the design of climate change-resilient farming systems. Agron. Sustain. Dev. 35, 869–890.

Alveranga, P., Mourinha, C., Farto, M., Santos, T., Palma, P., Sengo, J., Morais, M.C., Cunha-Queda, C., 2015. Sewage sludge, compost and other representative organic wastes as agricultural soil amendments; benefits versus limiting factors. Waste Manag. 40, 44–52.

Amadou Binta, B.A., Barbier, B., 2015. Economic and environmental performances of or- ganic farming system compared to conventional farming system: a case farm model to simulate the horticultural sector of the Niayes region in Senegal. J Horticul- ture 2,

152.
Atkinson, C.J., Fitzgerald, J.D., Hipps, N.A., 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant Soil 337, 1. https://doi.org/10.1007/s11104-010-0464-5.
Auerswald, K., Fiener, P., Dikau, R., 2009. Rates of sheet and rill erosion in Germany - a meta-analysis. Geomorphology 111, 182–193.
Baccelli, I., Mauch-Mani, B., 2017. When the story proceeds backward: the discovery of endogenous β-aminobutyric acid as the missing link for a potential new plant hor- mone. Com. Integr. Biol. 10, 2.
Bachinger, J., Zander, P., 2007. ROTOR: a tool for generating and evaluating crop rotations for organic farming systems. Eur. J. Agron. 26, 130–143.
Balmer, A., Pastor, V., Gamir, J., Flors, V., Mauch-Mani, B., 2015. The 'prime-ome': towards a holistic approach to priming. Trends Plant Sci. 20, 443–452.
Bàrberi, P., 2002. Weed management in organic agriculture: are we addressing the right issues? Weed Res. 42, 177–193. https://doi.org/10.1046/j.1365-3180.2002.00277.x.
Boer, M.P., Wright, D., Feng, L., Podlich, D.W., Luo, L., Cooper, M., van Eeuwijk, F.A., 2007. A mixed-model quantitative trait loci (QTL) analysis for multiple-environment trial data using environmental covariables for QTL-by-environment interactions, with an example in maize. Genetics 177 (3), 1801–1813.
Bonfante, P., Genre, A., 2010. Mechanisms underlying beneficial plant–fungus interactions in mycorrhizal symbiosis. Nat. Commun. 1, 48. https://doi.org/10.1038/ncomms1046.
Brisson, N., Gary, C., Justes, E., Roche, R., Mary, B., et al., 2003. An overview of the crop model stics. Eur. J. Agron. 18 (3–4), 309–332.
Bruinsma J (2017) World Agriculture: Towards 2015/2030. An FAO Study. Edited by Jelle Bruinsma. 1st edition, (eBook Published 25 September 2017, Routledge, London, UK).
Bybee-Finley, K.A., Ryan, M.R., 2018. Advancing intercropping research and practices in industrialized agricultural landscapes. Agriculture 8, 80.
Cabral, C., Ravnskov, S., Tringovska, I., Wollenweber, B., 2016. Arbuscular mycorrhizal fungi modify nutrient allocation and composition in wheat (Triticum aestivum L.) sub- jected to heat stress. Plant Soil 408, 385–399. https://doi.org/10.1007/s11104-016-2942-x.
Cabral, C., Wollenweber, B., António, C., Rodrigues, A.M., Ravnskov, S., 2018. Aphid infes- tation in the phyllosphere affects primary metabolic profiles in the arbuscular mycorrhizal hyphosphere. Sci. Rep. 8, 14442. https://doi.org/10.1038/s41598-018-32670-1.
Chabbi, A., Lehmann, J., Ciais, P., Loescher, H.W., Cotrufo, M.F., Don, A., SanClements, M.,
Schipper, L., Six, J., Smith, P., Rumpel, C., 2017. COMMENTARY: aligning agriculture and climate policy. Nat. Clim. Chang. 7, 307.
Chan, K.X., Phua, S.Y., Crisp, P., McQuinn, R., Pogson, B.J., 2016. Learning the languages of the chloroplast: retrograde signaling and beyond. Annu. Rev. Plant Biol. 67, 25–53.
Chandler, D., Bailey, A.S., Tatchell, G.M., Davidson, G., Greaves, J., Grant, W.P., 2011. The development, regulation and use of biopesticides for integrated pest management. Phil Trans Roy Soc B 366, 1987–1998.
Chhipi-Shrestha, G., Rodriguez, M., Sadiq, R., 2019. Selection of sustainable municipal water reuse applications by multistakeholders using game theory. STotEn 650, 2512–2526.
Chmelíková, L., Wolfrum, S., Schmid, H., Hejcman, M., Hülsbergen, K.J., 2015. Seasonal de- velopment of biomass yield in grass–legume mixtures on different soils and development of above- and belowground organs of Medicago sativa. Arch. Agron. Soil Sci. 61 (3), 329–346.
https://doi.org/10.1080/03650340.2014.936854.
Christou, A.T., Agüera, A., Bayona, J.M., Cytryn, E., Fotopoulos, V., Lambropoulou, D., Manaia, C., Michael, C., Revitt, M., Schröder, P., Fatta-Kassinos, D., 2017. The potential implications of reclaimed wastewater reuse for irrigation on the agricultural environ- ment: the knowns and unknowns of the fate of antibiotics and antibiotic resistant bacteria and resistance genes - a review. Water Res. 123, 448–467. https://doi.org/ 10.1016/j.watres.2017.07.004.
Clark, S., Klonsky, K., Livingston, P., Temple, S., 1999. Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacra- mento Valley. Am. J. Altern. Agriculture 14 (3), 109–121.

Cong, L., Ran, F.A., Cox, D., Lin, S., Barretto, R., Habib, N., Hsu, P.D., Wu, X., Jiang, W., Marraffini, L.A., Zhang, F., 2013. Multiplex genome engineering using CRISPR/Cas systems. Science 339, 819–823.

Couillerot, O., Ramírez-Trujillo, A., Walker, V., von Felten, A., Jansa, J., Maurhofer, M., Défago, G., Prigent-Combaret, C., Comte, G., Caballero-Mellado, J., Moënne-Loccoz, Y., 2013. Comparison of prominent Azospirillum strains in Azospirillum-Pseudomo- nas-Glomus consortia for promotion of maize growth. Appl. Microbiol. Biotechnol. 97, 4639–4649. https://doi.org/10.1007/s00253-012-4249-z.

Czajkowski, R., Smolarska, A., Ozymko, Z., 2017. The viability of lytic bacteriophage ΦD5 in potato-associated environments and its effect on Dickeya solani in potato (Solanum tuberosum L.) plants. PLoS ONE 12, e0183200. https://doi.org/10.1371/journal.pone.0183200.

Davletova, S., Schlauch, K., Coutu, J., Mittler, R., 2005. The zinc-finger protein Zat12 plays a central role in reactive oxygen and abiotic stress signaling in Arabidopsis. Plant Phys- iol. 139 (2), 847–856.

De Almeida Silva, et al., 2012. Breeding for Water Use Efficiency. Plant Breeding for Abiotic Stress Tolerance. Springer-Verlag, Berlin Heidelberg.

De Gisi S, Casella P, Cellamare CM, Ferraris M, Petta L, Notarnicola M (2017) Wastewater reuse. In: Abraham, M.A. (Ed.), Encyclopedia of Sustainable Technologies. Elsevier, pp. 53–68.

van der Heijden MG, Martin FM, Selosse MA, Sanders IR (2015) Mycorrhizal ecology and evolution: the past, the present, and the future. New Phytol. 2015 Mar;205(4): 1406–23.

Dogliotti, S., Rossing, W.A.H., van Ittersum, M.K., 2003. ROTAT, a tool for systematically generating crop rotations. Eur. J. Agron. 19, 239–250.

Duchene, O., Vian, J.F., Celette, F., 2017. Intercropping with legume for agroecological cropping systems: complementarity and facilitation processes and the importance of soil microorganisms. A review. Agriculture Ecosystems & Environment 240, 148–161.

EC, 2011. Sustainable Food Consumption and Production in a Resource-constrained World - The 3rd SCAR Foresight Exercise. Publications Office of the European Union, Luxembourg.

EC (2016) Guidelines on integrating water reuse into water planning and management in the context of the WFD. Common implementation strategy for the water framework directive and the flood directive. http://www.ec.europa.eu/environment/water/pdf/ Guidelines_on_water_reuse.pdf.

EC (2018) Proposal for a regulation of the European parliament and of the council on minimum requirements for water reuse. https://ec.europa.eu/info/law/better-regulation/initiatives/com-2018-337_en

Ellouze, W., Taheri, A.E., Bainard, L.D., Yang, C., Bazghaleh, N., Navarro-Borrell, A., Hanson, K., Hamel, C., Soil fungal resources in annual cropping systems and their potential for management, BioMed Research International, 2014. Article ID, 531824 https://doi.org/10.1155/2014/531824.

EPA (2012) Guidelines for Water Reuse. EPA/600/R-12/618, US Environmental Protection Agency.

Esau, T., Zaman, Q., Groulx, D., Chang, Y., Schumann, A., Havard, P., 2017. Machine vision for spot-application of agrochemical in wild Blueberry fields. Advances in Animal Bio- sciences: Precision Agriculture (ECPA) 8 (2), 272–276.

Estendorfer, J., Stempfhuber, B., Haury, P., Vestergaard, G., Rillig, M.C., Joshi, J., Schröder, P., Schloter, M., 2017. The influence of land use intensity on the plant-associated microbiome of Dactylis glomerata L. Front. Plant Sci. https://doi.org/10.3389/fpls.2017.00930 (21 June 2017).

FAO, 2011. Global food losses and food waste – Extent, causes and prevention. Rome. FAO, 2017. The future of food and agriculture – Trends and challenges. Rome.

FAO and ITPS, 2015. Status of the World's Soil Resources (SWSR) - Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils. Rome, Italy.

FAO. 2017. The future of food and agriculture – Trends and challenges. Rome. Farooq, M., Jabran, K., Cheema, Z.A., Wahid, A., Siddique, K.H.M., 2011. The role of allelopathy in agricultural pest management. Pest Manag. Sci. 67, 493–506.

Farrell, M., Jones, D.L., 2009. Critical evaluation of municipal waste composting and potential compost markets. Bioresour. Technol. 100, 4301–4310.

Ferrari, A.E., Ravnskov, S., Larsen, J., Tønnersen, T., Maronna, R.A., Wall, L.G., 2015. Crop rotation and seasonal effects on fatty acid profiles of neutral and phospholipids extracted from no-till agricultural soils. Soil Use Manag. 31, 165–175.

Fischer, G., Tubiello, F.N., van Velthuizen, H., Wiberg, D.A., 2007. Climate change impacts on irrigation water requirements: effects of mitigation 1990–2080. Techn. Forecast. Soc. 74, 1083–1107.

Fox, J.W., 2003. The long-term relationship between plant diversity and total plant biomass depends on the mechanism maintaining diversity. OIKOS 102, 630–640.

Friedman, J., Barrett, S.C., 2009. Wind of change: new insights on the ecology and evolution of pollination and mating in wind-pollinated plants. Ann. Bot. 103, 1515–1527.

Gámiz, B., López-Cabeza, R., Facenda, G., Velarde, P., Hermosín, M.C., Cox, L., Celis, R., 2016. Effect of synthetic clay and biochar addition on dissipation and enantioselectivity of tebuconazole and metalaxyl in an agricultural soil: laboratory and field experiments. Agric. Ecosyst. Environ. 230, 32–41.

Geisseler, D., Scow, K.M., 2014. Long-term effects of mineral fertilizers on soil microorganisms – a review. Soil Biol. Biochem. 75, 54–63.

Gianinazzi, S., Gollotte, A., Binet, M.N., van Tuinen, D., Redecker, D., Wipf, D., 2010. Agroecology: the key role of arbuscular mycorrhizas in ecosystem services. Mycorrhiza 20, 519–530.

Głowacka, K., Kromdijk, J., Kucera, K., Xie, J., Cavanagh, A.P., Leonelli, L., Leakey, A.D.B., Ort,

D.R., Niyogi, K.K., Long, S.P., 2018. Photosystem II subunit S overexpression increases the efficiency of water use in a field-grown crop. Nat. Commun. https://doi.org/10.1038/s41467-018-03231-x.

Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Phil Trans R Soc Lond Biol Sci. 369 (1639), 20120273.

Gopal, M., Gupta, A., 2016. Microbiome selection could spur next-generation plant breeding strategies. Front Microbiol. 7, 1971.

Grant, F.R., Jackson, B.S., Kiniry, J.R., Arkin, G.F., 1989. Water deficit timing effects on yield components in maize. Agron. J. 81, 61–65.

Hargreaves, J.C., Adl, M.S., Warman, P.R., 2008. A review of the use of composted municipal solid waste in agriculture. Agric. Ecosyst. Environ. 123, 1–14.

Hartman, K., van der Heijden M.G.A., Wittwer R.A., Banerjee S., Walser J.C., Schlaeppi K., 2018. Cropping practices manipulate abundance patterns of root and soil microbiome members paving the way to smart farming. Microbiome 6 (1), 74 6:14. Erratum in: Microbiome.

Hartmann, A., Rothballer, M., Hense, B., Schröder, P., 2014. Bacterial quorum sensing compounds are important modulators of microbe-plant interactions. Frontiers in Plant Sci.-Plant-Microbe Interaction. doi https://doi.org/10.3389/fpls.2014. 00131.

Heath, S.K., Soykan, C.U., Velas, K.L., Kelsey, R., Kross, S.M., 2017. A bustle in the hedgerow: Woody field margins boost on farm avian diversity and abundance in an intensive agricultural landscape. Biol. Conserv. 212, 153–161.

Hernández-Reyes, C., Schenk, S.T., Neumann, C., Kogel, K.H., Schikora, A., 2014. N-acyl-homoserine lactones-producing bacteria protect plants against plant and human pathogens. Microb. Biotechnol. 7, 580–588. https://doi.org/10.1111/1751-7915.12177 (2014 Nov).

Hettiarachchi H, Ardakanian R, (Eds) (2016) Safe use of wastewater in agriculture: good practice examples. United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES), ISBN 978-3-944863-30-6.

Hohmann, P., Messmer, M., 2017. Breeding for mycorrhizal symbiosis: focus on disease resistance. Euphytica 213 (113), 1–11.

Howell, J.C., Hazzard, R.V., 2014. 2013 New England vegetable management guide. Univ. Massachusetts Ext. Publ 18.

Hu, L., Robert, C.A.M., Cadot, S., Zhang, X., Ye, M., Li, B., Manzo, D., Chervet, N., Steinger, T., van der Heijden, M.G.A., Schlaeppi, K., Erb, M., 2018. Root exudate metabolites drive plant-soil feedbacks on growth and defense by shaping the rhizosphere microbiota. Nat. Commun. 9, 2738. https://doi.org/10.1038/s41467-018-05122-7.

Humburg, D., 2016. Chapter 37: Combine adjustments to reduce harvest losses. In: Clay, D.E., Carlson, C.G., Clay, S.A., Byamukama, E. (Eds.), iGrow Corn: Best Management Practices. South Dakota State University.

IPES-Food, 2016. From Uniformity to Diversity: A Paradigm Shift From Industrial Agricul- ture to Diversified Agroecological Systems. Intl Panel of Experts on Sustainable Food systems. www.ipes-food.org.

ISO/TC 282/SC 1 Standards catalogue. Treated wastewater reuse for irrigation, https://www.iso.org/committee/5148678/x/catalogue/

Jabran, K.G., Mahajan, V., Sardana, B., Chauhan, S., 2015. Allelopathy for weed control in agricultural systems. Crop Prot. 72, 57–65.

Jaramillo, M.F., Restrepo, I., 2017. Wastewater reuse in agriculture: a review about its limitations and benefits. Sustainability 2017 (1734), 9. https://doi.org/10.3390/ su9101734.

Jiao, W.B., Schneeberger, K., 2017. The impact of third generation genomic technologies on plant genome assembly. Curr. Opin. Plant Biol. 36, 64–70.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijyman, A.S., Ritchie, J.T., 2003. The DSSAT cropping system model. Eur. J. Agron. 18 (3), 235–265. https://doi.org/10.1016/S1161-0301(02)00107-7.

Kahiluoto, H., Ketoja, E., Vestberg, M., 2009. Contribution of arbuscular mycorrhiza to soil quality in contrasting cropping systems. Agric. Ecosyst. Environ. 134, 36–45.

Kamburova, V.S., Nikitina, E.V., Shermatov, S.E., Buriev, Z.T., Kumpatla, S.P., Emani, C., et al., 2017. Genome editing in plants: an overview of tools and applications. Int. J. Agron. 2017, 15.

Kang, J., Hwang, J.U., Lee, M., Kim, Y.Y., Assmann, S.M., Martinoia, E., Lee, Y., 2010. PDR- type ABC transporter mediates cellular uptake of the phytohormone abscisic acid. PNAS 107 (5), 2355–2360.

Karpinski, S., Escobar, C., Karpinska, B., Creissen, Mullineaux, P.M., 1997. Photosynthetic electron transport regulates the expression of cytosolic ascorbate peroxidase genes in Arabidopsis during excess light stress. Plant Cell 9 (4), 627–640.

Keding, G.B., Schneider, J., 2013. Production and processing of foods as core aspects of nutrition-sensitive agriculture and sustainable diets. Food Security 5 (6), 825–846.

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B., Fresco, L.O., 2016. The significance of soils and soil science towards re- alization of the United Nations Sustainable Development Goals. SOIL 2, 111–128.

Khan, A., Valpuri, S., Dorcus, G., 2016. Genome-assisted breeding for drought resistance.
Current Genomics 17, 330–342.

Kiær, L.P., Skovgaard, IbM, Østergard, H., 2009. Grain yield increase in cereal variety mix- tures: a meta-analysis of field trials. Field Crop Res. 114, 361–373.

Kovacs-Hostyanszki, A., Espındola, A., Vanbergen, A.J., Settele, J., Kremen, C., Dicks, L.V.,
2017. Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. Ecol. Lett. 20, 673–689.

Lazzaro, L., Otto, S., Zanin, G., 2008. Role of hedgerows in intercepting spray drift: evaluation and modelling of the effects. Agric. Ecosyst. Environ. 123 (4), 317–327.

Lee, S.H., Oh, H.W., Fang, Y., An, S.B., Park, D.S., Song, H.H., Oh, S.R., Kim, S.Y., Kim, S., Kim,
N., Raikhel, A.S., 2015. Identification of plant compounds that disrupt the insect juve- nile hormone receptor complex. Proc. Natl. Acad. Sci. 112 (6), 1733–1738.

Licciardello, M., Milani, M., Consoli, S., Pappalardo, N., Barbagallo, S., Cirelli, G., 2018. Wastewater tertiary treatment options to match reuse standards in agriculture. Agric. Water Manag. 210, 232–242.

López-Cabeza, R., Cornejo, J., Celis, R., 2016. Evaluation of an organo-layered double hydroxide and two organic residues as amendments to immobilize metalaxyl enantiomers in soils: a comparative study. J. Environ. Manag. 181, 135–145.

López-Cabeza, R., Gámiz, B., Cornejo, J., Celis, R., 2017. Behavior of the enantiomers of the herbicide imazaquin in agricultural soils under different application regimes. Geoderma 293, 64–72.

Lotter, D.W., 2003. Organic agriculture. J. Sustain. Agric. 21, 59–128.

Lucini, L., Colla, G., Miras Moreno, M.B., Bernardo, L., Cardarelli, M., Terzi, V., Bonini, P., Rouphael, Y., 2019. Inoculation of Rhizoglomus irregulare or Trichoderma atroviride dif- ferentially modulates metabolite profiling of wheat root exudates. Phytochemistry 157, 158–167.

Luo, L., Xia, H., Lu, B.R., 2019. Editorial: crop breeding for drought resistance. Front. Plant Sci. https://doi.org/10.3389/fpls.2019.00314 (20 March 2019).

Lyon GD (2007) Agents that can elicit induced resistance. In: Induced resistance for plant defense, In: Walters DR, Newton AC, Lyon GD (Eds.), Blackwell, pp. 9-29.

Magdoff, F., Weil, R., 2004. Soil organic matter management strategies. In: Magdoff, F., Weil, R. (Eds.), Soil Organic Matter in Sustainable Agriculture. CRC Press, Boca Raton, pp. 44–65.

Manavalan, L.P., Guttikonda, S.K., Tran, L.S.P., Nguyen, H.T., 2009. Physiological and molec- ular approaches to improve drought resistance in soybean. Plant Cell Physiol 50, 1260–1276.

Mancosu, N., Snyder, R.L., Kyriakakis, G., Spano, D., 2015. Water scarcity and future chal- lenges for food production. Water 7, 975–992.

Mateo-Sagasta J, Mariani Zadeh S, Turral H (2017) Water pollution from agriculture: global review. Food and Agriculture Organization of the United Nations: (35 pp.)

Mauch-Mani, B., Baccelli, I., Luna, E., Flors, V., 2017. Defense priming: an adaptive part of induced resistance. Ann.Rev.Plant Biol. 68, 485–512.

MEA (2005) Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Biodiversity Synthesis. Washington, D.C.: World Resources Institute.

Mekonnen, M., Hoekstra, A.Y., 2016. Four billion people facing severe water scarcity. Science advances 2 (2), e1500323. https://doi.org/10.1126/sciadv.1500323.

Meneses, M., Pasqualino, J.C., Castells, F., 2010. Environmental assessment of urban waste- water reuse: treatment alternatives and applications. Chemosphere 81, 266–272.

Miao, Y., Lv, D., Wang, P., Wang, X.-C., Chen, J., Miao, C., Song, C.-P., 2006. An Arabidopsis glutathione peroxidase functions as both a redox transducer and a scavenger in abscisic acid and drought stress responses. Plant Cell 18 (10), 2749–2766.

Moran, N.A., Sloan, D.B., 2015. The Hologenome concept: helpful or hollow? PLoS Biol. 13 (12), e1002311. https://doi.org/10.1371/journal.pbio.1002311.

Morandin, L.A., Long, R.F., Kremen, C., 2016. Pest control and pollination cost benefit analysis of hedgerow restoration in a simplified agricultural landscape. J. Econ. Entomol. 109 (3), 1020–1027. https://doi.org/10.1093/jee/tow086.

Moshia, M.E., Khosla, R., Longchamps, L., Reich, R., Davis, J.G., Westfall, D.G., 2014. Preci- sion manure management across site-specific management zones: grain yield and economic analysis. Agron. J. 106, 2146–2156. https://doi.org/10.2134/agronj13.0400. Mundt, C.C., 2002. Use of multiline cultivars and cultivar mixtures for disease manage- ment. Annu. Rev. Phytopathol. 40, 381–410. https://doi.org/10.1146/annurev. phyto.40.011402.113723.

Murphy, B.R., Martin Nieto, L., Doohan, F.M., Hodkinson, T.R., 2015. Fungal endophytes enhance agronomically important traits in severely drought-stressed barley. J Agro Crop Sci 201, 419–427. https://doi.org/10.1111/jac.12139.

Murphy, B., Hodkinson, T., Doohan, F., 2017. A fungal endophyte consortium counterbalances the negative effects of reduced nitrogen input on the yield of field-grown spring barley. J. Agric. Sci. 155 (8), 1324–1331. https://doi.org/10.1017/S0021859617000417.

Nelson, R.A., Grist, P.G., Menz, K.M., Cramb, R.A., Paningbatan, E.P., Mamicpic, M.A., 1996. A cost-benefit analysis of hedgerow intercropping in the Philippine uplands using the SCUAF model. Agrofor. Syst. 35 (2), 203–220.

Nendel, C., Berg, M., Kersebaum, K., Mirschel, W., Specka, X., Wegehenkel, M., Wenkel, K.O., Wieland, R., 2011. The MONICA model: testing predictability for crop growth, soil moisture and nitrogen dynamics. Ecol. Model. 222 (9), 1614–1625.

Nepolean, T., Kaul, G., Mukri, G., Mittal, S., 2018. Genomics-enabled next-generation breeding approaches for developing system-specific drought tolerant hybrids in maize. Front. Plant Sci. https://doi.org/10.3389/fpls.2018.00361.

O'Neill, B.C., Riahi, K., Keppo, I., 2010. Mitigation implications of midcentury targets that preserve long-term climate policy options. ProcNatlAcadSci USA 107 (3), 1011–1016. https://doi.org/10.1073/pnas.0903797106.

Osakabe, Y., Osakabe, K., Shinozaki, K., Tran, L.S.P., 2014. Response of plants to water stress. Front. Plant Sci. 5, 86.

Osakabe, Y., Watanabe, T., Sugano, S.S., Ueta, R., Ishihara, R., Shinozaki, K., Osakabe, K., 2016. Optimization of CRISPR/Cas9 genome editing to modify abiotic stress responses in plants. Sci. Rep. 26, 26685. https://doi.org/10.1038/srep26685.

Pannell, D.J., 1999. Social and economic challenges in the development of complex farm- ing systems. Agrofor. Syst. 45 (1–3), 395–411.

Pastor, V., Balmer, A., Gamir, J., Flors, V., Mauch-Mani, B., 2014. Preparing to fight back: generation and storage of priming compounds. Front. Plant Sci. 5, 295.

Pavela, R., 2016. History, presence and perspective of using plant extracts as commercial botanical insecticides and farm products for protection against insects – a review. Plant Protect. Sci. 52, 229–241.

Pellegrino, E., Opik, M., Bonari, E., Ercoli, L., 2015. Responses of wheat toarbuscular mycorrhizal fungi: a meta-analysis of field studies from 1975 to 2013. Soil Biol. Biochem. 84, 210–217.

Persson, T., Kværnø, S., Höglind, M., 2015. Impact of soil type extrapolation on timothy grass yield under baseline and future climate conditions in southeastern Norway. Contribution to the CR Special: 'Modelling climate change impacts for food security'. CR 65, 71–86. https://doi.org/10.3354/cr01303.

Pinheiro, P.F., Queiroz, V.T.D., Rondelli, V.M., Costa, A.V., Marcelino, T.D.P., Pratissoli, D., 2013. Insecticidal activity of citronella grass essential oil on Frankliniella schultzei and Myzus persicae. Ciência e Agrotecnologia 37 (2), 138–144.

Pistocchi A, Aloe A, Dorati C, Alcalde Sanz L, Bouraoui F, Gawlik B, Grizzetti B, Pastori M, Vigiak O (2018) The potential of water reuse for agricultural irrigation in the EU. A Hydro-economic Analysis, EUR 28980 EN, EU Publ Office, Luxembourg, 2018, ISBN 978-92-79-77210-8.

Pujari, D., Badal, B., Mrinmoy, D., 2013. Insect pest management in organic agriculture. In- ternational Journal of Plant Protection 6 (2), 467–472.

Rankl, S., Gunsé, B., Sieper, T., Schmid, C., Poschenrieder, C., Schröder, P., 2016. Microbial homoserine lactones (AHLs) are effectors of root morphological changes in barley. Plant Sci. 253, 130–140.

Rao, M.R., Sharma, M.M., Ong, C.K., 1991. A tree/crop interface design and its use for evaluating the potential of hedgerow intercropping. Agrofor. Syst. 13 (2), 143–158.

Ravnskov, S., Larsen, J., 2016. Functional compatibility in cucumber mycorrhizas in terms of plant growth performance and foliar nutrient composition. Plant Biol. 18 (5), 816–823.

Reddy, N., Rama, R., Ragimasalawada, M., Sabbavarapu, M.M., Nadoor, S., Patil, J.V., 2015. Detection and validation of stay-green QTL in post-rainy sorghum involving widely adapted cultivar, M35-1 and a popular stay-green genotype B35. BMC Genomics 15 (1), 909.

Reents, H.J., Küstermann, B., Kainz, M., 2008. Sustainable land use by organic and inte- grated farming systems. In: Schröder, P., Munch, J.C., Pfadenhauer, H. (Eds.), Perspec- tives for Agroecosystem Management. Elsevier, Balancing Environmental and Socio- economic Demands, pp. 17–24.

Reichel, R., Wei, J., Islam, S.M., Schmid, C., Wissel, H., Schröder, P., Schloter, M., Brüggemann, N., 2018. Potential of wheat straw, spruce sawdust, and lignin as high organic carbon soil amendments to improve agricultural nitrogen use efficiency and retention capacity. Front Plant Sci. 9, 900. https://doi.org/10.3389/ fpls.2018.00900.

Reiss, E.R., Drinkwater, L.E., 2018. Cultivar mixtures: a meta-analysis of the effect of intra-specific diversity on crop yield. Ecol. Appl. 28 (1), 62–77.

Renugadevi, G., Ramanathan, T., Thirunavukkarasu, P., 2013. Studies on effects of Andrographis paniculata (Burm. f.) and Andrographis lineata nees (Family: Acanthaceae) extracts against two mosquitoes Culex quinquefasciatus (Say.) and Aedes aegypti (Linn.). Asian Pac J Trop Med 6 (3), 176–179.

Rillig, M.C., Sosa-Hernández, M.A., Roy, J., Aguilar-Trigueros, C.A., Vályi, K., Lehmann, A., 2016. Towards an integrated mycorrhizal technology: harnessing mycorrhiza for sustainable intensification in agriculture. Front. Plant Sci. 7, 1625.

Rillig, M.C., Aguilar-Trigueros, C.A., Camenzind, T., Cavagnaro, T.R., Degrune, F., Hohmann, P., Lammel, D.R., Mansour, I., Roy, J., Heijden, M.G.A., et al., 2019. Why farmers should manage the arbuscular mycorrhizal symbiosis. A response to Ryan & Graham (2019). New Phytologist. https://doi.org/10.1111/nph.15602 (in press).

Rumpel, C., Lehmann, J., Chabbi, A., 2018. '4 per 1,000' initiative will boost soil carbon for climate and food security. Nature 553, 27.

Ryan, M.H., Graham, J.H., 2018. Little evidence that farmers should consider abundance or diversity of arbuscular mycorrhizal fungi when managing crops. New Phytol. 220, 1092–1107.

Ryan, M.H., Graham, J.H., Morton, J.B., Kirkegaard, J.A., 2019. Research must use a systems agronomy approach if management of the arbuscular mycorrhizal symbiosis is to contribute to sustainable intensification. New Phytol. https://doi.org/10.1111/ nph.15600.

Sabadin, P.K., Malosetti, M., Boer, M.P., Tardin, F.D., Santos, F.G., Guimarães, C.T., Gomide, R.L., Andrade, C.L., Albuquerque, P.E., Caniato, F.F., Mollinari, M., Margarido, G.R., Oliveira, B.F., et al., 2012. Studying the genetic basis of drought tolerance in sorghum by managed stress trials and adjustments for phenological and plant height differ- ences. Theor. Appl. Genet. 124 (8), 1389–1402.

Salgot, M., Folch, M., 2018. Wastewater treatment and water reuse. Current Opinion in Environmental Science & Health 2018 (2), 64–74.

Saliba, R., Callieris, R., D'Agostino, D., Romac, R., Scardigno, A., 2018. Stakeholders' attitude towards the reuse of treated wastewater for irrigation in Mediterranean agriculture. Agr Wat Man. 204, 60–68.

Santhanam, R., Luu, V.T., Weinhold, A., Goldberg, J., Oh, Y., Baldwin, I.T., 2015. Native root- associated bacteria rescue a plant from a sudden-wilt disease that emerged during continuous cropping. Proc. Natl. Acad. Sci. U. S. A. 112, E5013–E5020. https://doi. org/10.1073/pnas.1505765112.

Sapkota, A.R., 2018. Water reuse, food production and public health: adopting transdisci- plinary, systems-based approaches to achieve water and food security in a changing climate. Environmental Research https://doi.org/10.1016/j.envres.2018.11.003 (Available online 13 November 2018).

Saveyn, H., Eder, P., 2014. End-of-waste Criteria for Biodegradable Waste Subjected to Bi- ological Treatment (Compost & Digestate): Technical Proposals. JR Scientific and Pol- icy Reports. European Comission – Joint Research Centre, Luxembourg.

SCBD (2018) Convention on Biological Diversity. (www.cbd.int) Secretariat of the Con- vention of Biodiversity, UN, Vienna.

Schepers, J., Shanahan, J., Luchiari, A., 2000. Precision agriculture as a tool for sustainability. In: Balázs, E., et al. (Eds.), Biological Resource Management Connecting Science and Policy. Springer, Berlin, Heidelberg.

Schröder, P., Navarro Avino, J., Azaizeh, H., Golan Goldhirsh, A., DiGregorio, S., Komives, T., Langergraber, G., Lenz, A., Maestri, E., Memon, A., Ranalli, A., Sebastiani, L., Smrcek, S., Vanek, T., Vuillemier, S., Wissing, F., 2007. Position paper: using phytoremediation technologies to upgrade waste water treatment in Europe. ESPR 14 (7), 490–497.

Schröder, P., Huber, B., Reents, H.J., Munch, J.C., Pfadenhauer, J., 2008. Outline of the Scheyern project. In: Schröder, P., Pfadenhauer, J., Munch, J.C. (Eds.), Perspectives for Agroecosystem Management – Balancing Environmental and Socio-economic De- mands. Elsevier, Amsterdam, NL, pp. 3–10.

Schröder, P., Beckers, B., Daniels, S., Gnädinger, F., Maestri, E., Marmiroli, N., Mench, M., Millan, R., Obermeier, M.M., Oustriere, N., Persson, T., Poschenrieder, C., Rineau, F., Rutkowska, B., Schmid, T., Szulc, W., Witters, N., Sæbø, A., 2017. Intensify production, transform biomass to energy and novel goods and protect soils in Europe – a vision how to mobilize marginal lands. Sci. Total Environ. 616-617, 1101–1123. https://doi.org/10.1016/j.scitotenv.2017.10.209 2018 Mar.

Semenov, M.A., Halford, N.G., 2009. Identifying target traits and molecular mechanisms for wheat breeding under a changing climate. Journal of Experimental Botany, Vol- ume 60 (10), 2791–2804. https://doi.org/10.1093/jxb/erp164.

Slaughter, A., Daniel, X., Flors, V., Luna, E., Hohn, B., Mauch-Mani, B., 2012. Descendants of primed Arabidopsis plants exhibit resistance to biotic stress. Plant Physiol. 158 (2), 835–843 (2012 Feb).

Smith, F.A., Smith, S.E., 2011. What is the significance of the arbuscular mycorrhizal colo- nisation of many economically important crop plants? Plant Soil 348, 63–79.

Smith, L.G., Williams, A.G., Pearce, B.D., 2015. The energy efficiency of organic agriculture: a review Renewable Agriculture and Food Systems 30, 280–301.

Spehn, E.M., Hector, A., Joshi, J., et al., 2005. Ecosystem effects of biodiversity manipulations in European grasslands. Ecol. Monogr. 75, 37–63.

Streeter, J.G., 1994. Failure of inoculant rhizobia to overcome the dominance of indigenous strains for nodule formation. Can. J. of Microbiology 40 (7), 513–522. https://doi.org/10.1139/m94-084.

Svitashev, S., Young, J.K., Schwartz, C., Gao, H., Falco, S.C., Cigan, A.M., 2015. Targeted mu- tagenesis, precise gene editing, and site-specific gene insertion in maize using Cas9 and guide RNA. Plant Physiol. 169 (2), 931–945.

Svitashev, S., Schwartz, C., Lenderts, B., Young, J.K., Mark Cigan, A., 2016. Genome editing in maize directed by CRISPR–Cas9 ribonucleoprotein complexes. Nature Communic. 7, 13274.

Teodosiu, C., Gilca, A.F., Barjoveanu, G., Fiore, S., 2018. Emerging pollutants removal through advanced drinking water treatment: a review on processes and environmen- tal performances assessment. J. Clean. Prod. 197, 1210–1221.

Thirkell, T.J., Charters, M.D., Elliott, A.J., Sait, S.M., Field, K.J., 2017. Are mycorrhizal fungi our sustainable saviours? Considerations for achieving food security. J. Ecol. 105, 121–129.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustain- ability and intensive production practices. Nature 418, 671. https://doi.org/10.1038/ nature01014.

Timmusk, S., Behers, L., Muthoni, J., Muraya, A., Aronsson, A.C., 2017. Perspectives and challenges of microbial application for crop improvement. Front. Plant Sci. 8, 49. https://doi.org/10.3389/fpls.2017.00049.

Toju, H., Peay, K.G., Yamamichi, M., Narisawa, K., Hiruma, K., Naito, K., Fukuda, S., Ushio, M., Nakaoka, S., Onoda, Y., Yoshida, K., Schlaeppi, K., Bai, Y., Sugiura, R., Ichihashi, Y., Minamisawa, K., Kiers, E.T., 2018. Core microbiomes for sustainable agroecosystems. Nat Plants 4, 247–257. https://doi.org/10.1038/s41477-018-0139-4.

UNESCO, 2009. The United Nations World Water Development Report 3: Water in a Changing World. Earthscan, Paris and London.

Ussiri, D.A.N., Lal, R., 2018. The role of soil management and restoration in advancing sustainable development goals. In: Lal, R., Horn, R., Kosaki, T. (Eds.), Soil and Sustainable Development Goals. Catena, Stuttgart, pp. 61–81 chapter 5.

Vandenkoornhuyse, P., Quaiser, A., Duhamel, M., Le Van, A., Dufresne, A., 2015. The importance of the microbiome of the plant holobiont. New Phytol. 206 (4), 1196–1206. https://doi.org/10.1111/nph.13312.

Venghaus, S., Hake, J.F., 2018. Nexus thinking in current EU policies – the interdepen- dencies among food, energy and water resources. Environ. Sci. Pol. 90, 183–192.

Verbruggen, N., Villarroel, R., Van Montagu, M., 1993. Osmoregulation of a pyrroline-5-carboxylate reductase gene in Arabidopsis thaliana. Plant Physiol. 103 (3), 771–781.

Vergine, P., Salerno, C., Libutti, A., Beneduce, L., Gatta, G., Berardi, G., Pollice, A., 2017. Clos- ing the water cycle in the agro-industrial sector by reusing treated wastewater for irrigation. J. Clean. Prod. 164, 587–596.

Villaverde, J.J., Sevilla-Morán, B., Sandín-

España, P., LópezGoti, C., Alonso-Prados, J.L., 2014. Biopesticides in the framework of the European Pesticide Regulation (EC) No. 1107/2009. Pest Manag. Sci. 70, 2–5.

Wagg, C., Bender, S.F., Widmer, F., van der Heijden, M.A.G., 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proc. Natl. Acad. Sci. 111 (14), 5266–5270.

Wang, F.Z., Wang, Q.B., Kwon, S.Y., Kwak, S.S., Su, W.A., 2005. Enhanced drought tolerance of transgenic rice plants expressing a pea manganese superoxide dismutase. J. Plant Physiol. 162 (4), 465–472.

Wang, L., Yang, F., Yaoyao, E., Yuan, J., Raza, W., Huang, Q., Shen, Q., 2016. Long-term application of bioorganic fertilizers improved soil biochemical properties and microbial communities of an apple orchard soil. Front. Microbiol. 7, 1893 (eCollection 2016).

White, J., Hoogenboom, G., Kimball, B., Wall, G., 2011. Methodologies for simulating impacts of climate change on crop production. Field Crop Res. 124 (3), 357–368.

Wielemaker, R.C., et al., 2016. Harvest to harvest: recovering nutrients with new sanitation systems for reuse in urban agriculture. Resour. Conserv. Recycl. (12) https://doi.org/10.1016/j.resconrec.2016.09.015.

WHO, 2006. Guidelines for the Safe Use of Wastewater, Excreta and Greywater. World Health Organization, Geneva, CH.

Wie, X., Wie, X., Pan, J., Ali, T., Cui, Q., Guan, D., Meng, J., Mueller, N.D., Lin, E., Davis, S.J., 2018. Decreases in global beer supply due to extreme drought and heat. Nature Plants 4, 964–973. https://doi.org/10.1038/s41477-018-0263-1.

Willer, H., Yussefi, M., Sorensen, N., 2008. The World of Organic Agriculture: Statistics and Emerging Trends 2008. Earthscan, Bonn, Germany.

Wu W, Ma B (2015) Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: a review. Sci. Total Environ: 512–513.

WWAP (2015) The United Nations World Water Development Report 2015: water for a sustainable world. UN World Water Assessment Programme (WWAP). Paris, United Nations Educational, Scientifc and Cultural Organization.

Xing et al. A CRISPR/Cas9 toolkit for multiplex genome editing in plants. November 2014.

BMC Plant Biology 14(1):327.

Xu, L., Ravnskov, S., Larsen, J., Nilsson, R.H., Nicolaisen, M., 2012. Linking fungal communi- ties in roots, rhizosphere and soil to the health status of Pisum sativum. FEMS Microbiol. Ecology 82, 736–745.

Yang, L., Danzberger, J., Schöler, A., Schröder, P., Schloter, M., Radl, V., 2017. Dominant groups of potentially active bacteria shared by barley seeds become less abundant in root associated microbiome. Frontiers in Plant Sciences 8, 1005. https://doi.org/10.3389/fpls.2017.01005.

Yeo, E.T., Kwon, H.B., Han, S.E., Lee, J.T., Ryu, J.C., Byu, M.O., 2000. Genetic engineering of drought resistant potato plants by introduction of the trehalose-6-phosphate syn- thase (TPS1) gene from Saccharomyces cerevisiae. Mol Cells 10 (3), 263–268.

Yu, L., Nicolaisen, M., Larsen, J., Ravnskov, S., 2012. Molecular characterization of root-associated fungal communities in relation to plant health status of Pisum sativum using barcoded pyrosequencing. Plant Soil 357, 395–405.

Yu, L., Nicolaisen, M., Larsen, J., Ravnskov, S., 2013. Organic fertilization alters the commu- nity composition of root associated fungi in Pisum sativum. Soil Biol. Biochem. 58, 36–41.

Zahn, G., Amend, A.S., 2017. Foliar microbiome transplants confer disease resistance in a critically-endangered plant. PeerJ. 5, e4020. https://doi.org/10.7717/peerj.4020.

Zehnder, G., Gurr, G.M., Kühne, S., Wade, M.R., Wratten, S.D., Wyss, E., 2007. Arthropod pest management in organic crops. Annu. Rev. Entomol. 52, 57–80.

Zhalnina, K., Louie, K.B., Hao, Z., Mansoori, N., da Rocha, U.N., Shi, S., Cho, H., Karaoz, U., Loqué, D., Bowen, B.P., Firestone, M.K., Northen, T.R., Brodie, E.L., 2018. Dynamic root exudate chemistry and microbial substrate preferences drive patterns in rhizo- sphere microbial community assembly. Nat. Microbiol. 3, 470–480. https://doi.org/10.1038/s41564-018-0129-3.

Zhang W, Ricketts TH, Kremen C, et al.

Ecosystem services and dis-services to agriculture.
Ecol Econ. 64:253–60 2007. doi:https://doi.org/10.1016/j.ecolecon.2007.02.024 Zhang, N., Si, H.J., Wen, G., Du, H.H., Liu, B.L., Wang, D., 2011. Enhanced drought and salin-
ity tolerance in transgenic potato plants with a BADH gene from spinach. Plant Bio- tech, Rep. 5 (1), 71–77.

Zhao, J., Sun, H., Dai, H., Zhang, G., Wu, F., 2010. Difference in response to drought stress among Tibet wild barley genotypes. Euphytica 172, 395–403.

Zhao, J., Liu, J., Liang, H., Huang, J., Chen, Z., Nie, Y., Wang, C., Wang, Y., 2018. Manipulation of the rhizosphere microbial community through application of a new bio-organic fertilizer improves watermelon quality and health. PLoS One 13, e0192967.

Zhou, Q., Ravnskov, S., Jiang, D., Wollenweber, B., 2015. Changes in carbon and nitrogen allocation, growth and grain yield induced by arbuscular mycorrhizal fungi in wheat (Triticum aestivum L.) subjected to a period of water deficit. Plant Growth Regul. 75, 751–760.

Zolla, G., Badri, D.V., Bakker, M.G., Manter, D., Vivanco, J.M., 2013. Soil microbiomes vary in their ability to confer drought tolerance to Arabidopsis. Appl. Soil Ecol. 68, 1–9. https://doi.org/10.1016/j.apsoil.2013.03.007.

Zou, J.J., Wei, F.J., Wang, C., Wu, J.J., Ratnasekera, D., Liu, W.X., Wu, W.H., 2010. Arabidopsis calcium-dependent protein kinase CPK10 functions in abscisic acid and Ca2+-mediated stomatal regulation in response to drought stress. Plant Physiol. 154 (3), 1232–1243.