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Agronomic innovations for enhancing the yield potential of agricultural crops

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ABSTRACT

During the last few decades, multiple agronomic innovations have been introduced to boost up the yield potential of agricultural crops. Among these innovations, use of conservation agriculture approaches, and use of resource conservation technologies, e.g. direct-seeded rice (*Oryza sativa* L.), zero-tillage wheat (*Triticum aestivum* L.), laser land levelling, permanent raised beds, have been widely adopted across globe, to reduce the production cost and improve the soil health, the farmer profitability and decrease the water losses. Crop diversification with legumes and allelopathic crops for improving soil health and reducing weed pressure is also gaining momentum in different cropping systems. Cereal–legume intercropping for improving soil health, push-pull technology for control of crop pests, combination of soil–water balance and crop-phenological models for efficient water use, use of controlled and slow-release fertilizer for efficient nutrient management, use of arbuscular mycorrhizal fungi and rhizobacteria to improve nutrient-use efficiency and use of seed-enhancement techniques for improving stand establishment and crop performance are the prime agronomic innovation which are being promoted at farmer field to enhance farmer yield and profitability.

***Key words* :** Conservation agriculture, Push-pull technology, Slow release fertilizers, Water saving, Yield potential

INTRODUCTION

Agriculture is backbone of many developing nations across the globe. Food advancement remained key to feed ever-increasing population; Green Revolution being one of the major food advancements which saves millions from starvation. However, with onset of Green Revolution, fertilizer use was also increased which created several concerns related to environment. Green revolution also enhanced the cropping intensity due to short-duration cereal varieties, and water use for crop production was also enhanced in all regions of the world.

However, no significant yield advancements have been made genetically to further enhance the yield of crops; nonetheless different agronomic innovations have contributed a lot for maximizing the farmer income, improve crop yields and soil quality and improving crop response to climatic shocks. Among these innovations, use of conservation-agriculture approaches, and use of resource-conservation technologies (e.g. direct-seeded rice, zero-tillage wheat, laser-land levelling, permanent raised beds, mechanical rice transplanting, soil matric potential-based water application) have been widely adopted to re-boost crop yield with positive environmental footprints. Crop diversification of cereal-based systems with legumes and allelopathic crops have resulted in improved soil health and crop yields.

Push-pull technology, mostly adopted in sub-Saharan Africa, has been efficiently utilized to control stem-borer, striga weed and fall army worm. Controlled and slow-release fertilizer has been developed to maintain continuous supply of nutrients to crops with less loss of crop nutrients. Seed-enhancement techniques such as seed-priming and seed coating have resulted in improved stand establishment and crop performance on diverse soil types in many regions of the world. In this review article, we have reviewed different agronomic innovations which have got momentum in different regions of the world in improving yield of crops.

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CONSERVATION AGRICULTURE AND RESOURCE CONSERVATION TECHNOLOGIES

Conservation Agriculture (CA), based on 3 principles, viz. no/ minimum mechanical soil disturbance, crop diversification and maintains ace of residue mulch, tillage, has proved as a sustainable crop-production system across the globe. The spread of CA has reached 12.5% [180 million hectares (M ha) in 78 countries] of the total global cropped area during 2015–16 and this area was 106 M ha in 2008–09. Annual expansion in area under CA has been reported at 10.5 M ha since 2008-09 and most of the increase in area has been reported in North/ South America, New Zealand, Australia, Asia, Ukraine, Russia, Asia, Europe and Africa. The CA systems are being practiced on diverse soil types (90% sand to 80% clay), climates and different farm-size holdings (Kassam *et al.,* 2019). In south Asia, CA is being followed on an area of 5 M ha, mostly in the Indo-gangetic Plains where mostly rice and wheat are grown in rotation (Somasundaram *et al.,* 2020). In a meta-analysis of 9686 paired comparisons (year-site) studies, Jat *et al.* (2020) reported significant benefits in the adoption of CA component practices, either applied collective or separate. These benefits are either in the form of improvement in farmer net profits, improvement in soil health or reduction in global-warming potential. Gonzalez-Sanchez *et al.* (2019) estimated that, CA in Africa has potential to sequester 143 Tg of carbon per year, that is equal to 524 Tg of CO_2 per year.

In several countries, CA is not being followed with full principles and only some components have been adopted by farmers. For example, zero tillage in wheat has got momentum in South Asia owing to development of zero-till seed drills, happy seeders, turbo seeders and super seeders. Jat *et al.* (2020) reported that, zero tillage with retention of crop residues improved the mean yield, water-use efficiency and net economic returns by 5.8, 12.6 and 25.9% with a decrease of 12–33% in global warming potential. These responses were most favourable on loamy soils and in maize (*Zea mays* L.)–wheat rotations. Nawaz *et al.* (2019) and Rajanna *et al.* (2019) also summarized benefits of zero tillage in wheat in South Asia in terms of increase in yield, increase in farmer income, saving in cost, and an improvement in soil quality and water productivity and a decrease in global warming potential. Several other studies reported improvement in yield in zero tillage than plough tillage (Table 1).

Like zero tillage in wheat, direct seeding in rice is also an important resource-conservation technology which is getting momentum in rice–wheat zone of Asia; nonetheless, severe weed pressure and absence of varieties suitable for direct seeding are important factors dictating its wider scale adoptability (Nawaz *et al.,* 2019). Various previous studies documented increase in yield, reduction in CH_4 emission, early crop maturity, decrease in labour use and water saving in direct seeding of rice than flooded-rice production systems (Nawaz *et al.,* 2019; Ullah *et al.,* 2021). The other sustainable resource conservation technologies for rice and wheat include laser-land levelling, cultivation of rice and wheat on permanent raised beds, soil matric potential-based irrigation scheduling and mechanical rice transplanting (Bhatt *et al.,* 2021; Nawaz *et al.,* 2021).

CROP DIVERSIFICATION

Monoculture of different crops results in disease infestation, loss in soil fertility and low-system yields. However, crop diversification with legumes, allelopathic crops and vegetables helps improve crop health, economic yields, soil and environmental health, with an improvement in annual farmer income and yield stability. Currently, awareness has been developed among farming communities to include different legume and allelopathic crops in crop rotations to sustain the productivity of overall cropping systems (Ijaz *et al.,* 2019). Several studies

Table 1. Comparison of crop yields in no-till and plough-till systems under diverse soil types and climates

Country	Crop	Soil type	Yield (t/ha)		Reference
			Zero till	Plough till	
Poland	Winter wheat	Podsolic	5.70	6.80	Panasiewicz *et al.* (2020)
Tunisia	Durum wheat	Clayey	2.54	2.49	Souissi *et al.* (2020)
Iran	Soybean	Silt clay	3.57	3.13	Hosseini *et al.* (2016)
China	Spring wheat	Sandy loam	0.96	0.81	Sadiq *et al.* (2021)
Ethiopia	Maize	Clay loam	4.15	5.14	Adugna *et al.* (2019)
USA	Soybean	Sandy loam	3.50	3.80	Acharya *et al.* (2019)
China	Summer maize	Loamy	10.04	11.04	Ren *et al.* (2018)
Pakistan	Cotton	Hyperthermic and Typic Torrifluvents	3.15	2.87	Khan *et al.* (2015)
Iraq	Sorghum	Silty clay	3.99	4.16	Ramadhan and Mohsin (2021)
Bangladesh	Rice	Sandy loam	4.92	5.63	Rashid *et al.* (2019)

across the globe have reported improvement in farmers' profitability, soil health, yield stability and a reduction in pests (weeds and insect) and disease risks owing to crop diversification on diverse types and different soil conditions (Alam *et al.,* 2021; Farooq *et al.,* 2021; Sharma *et al.,* 2021).

Cereal–legume intercropping

Of late, intercropping has emerged as a new low-input agronomic innovation to ensure food and environmental security (Maitra *et al.,* 2021). Most of the documented benefits have been reported from the cereal–legume intercropping systems in the world. Tang *et al.* (2021) reviewed that, cereal–legume intercropping improved not only the phosphorus-use efficiency but also reduced the requirement of phosphorus by 21% in intercrops than sole crops. Khalid *et al.* (2021) also found that wheat–fababean (*Viccia faba* L.) (in winter) and sorghumn [*Sorghum bicolor* (L.) Moench]–Mungbean [*Vigna radiate* (L.) R. Wilczek] or pigeonpea [*Cajanus cajan* (L.) Millsp.] (in summer) was most productive cereal–legume intercrops at low- and high-moisture regimes. Improvement in soil health, economic yield and farmer profitability in cereal–legume intercrops has been reported in several studies (Feng *et al.,* 2021; Maitra *et al.,* 2021; Weih *et al.,* 2021).

High-efficiency irrigation management

The irrigational water resources are declining in the main crop-producing areas of the globe due to frequent droughts and increasing water competition between the industry, agriculture and the rural areas. Thus, high-efficiency irrigation management is the need of hour to fulfil the future demands of irrigation for crops. Drip/ trickle irrigation and sprinkler irrigation has been emerged as high-water efficient water-management systems for fulfiling irrigation needs of crops, especially in water-scare areas of the world. These systems have proven useful for orchards, vegetables and row crops.

In Pakistan, the high-efficiency irrigation systems proved effective in terms of water saving, reduced fertilizer use and enhancement in crop productivity by 50, 40 and 20–100%, respectively (Yasin *et al.,* 2021). Moreover, use of high–efficiency irrigation systems in Pakistan have resulted in an increase of 140, 35, 33 and 64% in net income for vegetables, citrus (*Citrus* sp.), guava (*Psidium guajava* L.) and row/ field crops, respectively, in Punjab, with an increase of 192% in water productivity. In 4 provinces of north-west China, meta-analysis of 22 studies showed that, drip irrigation can improve apple yield by 54.3%; while optimized drip irrigation methods (i.e. use of infiltration enhancing pipes and partial root zone drying) can enhance water-use efficiency by 17.2% (Zhang *et al.,* 2021).

Arbuscular mycorrhizal fungi and rhizobacteria

Arbuscular mycorrhizal fungi (AMF) and rhizobacteria are reported to improve crop performance under optimal and sub-optimal (abiotic and biotic stresses) conditions (Malhi *et al.,* 2021). In a recent study, Igiehon *et al.* (2021) reported that, use of rhizobacteria and AMF alleviated drought stress and enhanced seed size, seed yield and fat contents of soybean [*Glycine max* (L.) Merr.] owing to an improved belowground AMF spore number, increase in root mycorrhization and shoot relative water contents. Fahsi *et al.* (2021) reported that, the use of four strains of phosphorus-solubilizing bacteria, isolated from jujube [*Ziziphus lotus* (L.) Lam.], improved seed germination, wheat growth and zinc absorption. The uptake of potassium and nitrogen was also enhanced by 17%. Use of AMF and rhizobacteria has emerged as an innovative agronomic practice in improving crop yields under optimal and sub-optimal conditions. Many studies have reported that, use of rhizobacteria or AMF improved the performance of crops under drought stress (He *et al.,* 2020; Zhang *et al.,* 2020), heat stress (Yan *et al.,* 2021), heavy metal stress (Hao *et al.,* 2021) or salinity stress (Sagar *et al.,* 2021).

Combination of soil-water balance and crop-phenological models

The aim of irrigation scheduling is to improve the plant growth, economic yield and quality by providing plants with appropriate quantities of water at right time without losing precious water resources for future generations. There are different methods of irrigation scheduling which are based on (*i*) evaporation and water balance, (*ii*) plant-water status, (*iii*) soil-water status and (*iv*) crop-phenological models (with their pros and cons) (Gu *et al.,* 2020). Among these methods, a combined strategy of using soil-water balance and crop-phenological models might be a pragmatic approach to improve water productivity of crops (Pereira *et al.,* 2020). Such type of models have been tested for onion (*Allium cepa* L.) to predict future water demands (Schmidt and Zinkernagel, 2017), nonetheless comprehensive studies are needed to use this approach for other crops of economic importance.

Use of controlled and slow-release fertilizers

Use of controlled and slow-release fertilizers may help improve the fertilizer-use efficiency and improve crop yields with positive effects on N_2O emissions. Andrade *et al.* (2021) found that, use of controlled release urea and its blends promoted constant nitrogen uptake in maize plants. Biochar coated urea resulted in a reduction of nitrogen loss and improved the nitrogen-use efficiency (Jia *et al.,* 2021). Use of slow -elease fertilizers (urea coated with neem (*Azadirachta indica* A. Juss.), sulphur and bioactive sulphur, enhanced the wheat growth, seed yield and nitrogen use efficiency and decreased the nitrogen losses in an arid environment (Ghafoor *et al.,* 2021). Several other studies have reported that use of controlled and slow-release fertilizers improve the fertilizer-use efficiency and crop performance with reduction in losses of fertilizers (Rana *et al*., 2018; Feng *et al.,* 2021; Guo *et al.,* 2021a,b; Li *et al.,* 2021; Tian *et al.,* 2021).

Push-pull technology

Push-pull technology is an innovative agronomic practice developed in sub-Saharan Africa to reduce pests in crops of economic importance and it is being adopted by e”0.24 million farmers in East Africa. This innovative technique was first developed to control stem-borers and now it is being widely used to control striga weed and fall army worm (Midega *et al.,* 2018; Kuyah *et al.,* 2021). In this technology, the cereal crops are intercropped with *Desmodium* species (as push crop) and palisade grass [*Urochloa brizantha* (Hochst. Ex A. Rich) R. Webster; syn. *Brachiaria brizantha* (A. Rich.) Stapf] or Napier grass [*Cenchrus purpureus* (Schumach) Morrone; syn. *Pennisetum purpurem* Schumach.] is planted as border crop (Khan *et al.,* 2014). The species of *Desmodium* releases chemicals which repels not only stem-borer but also attracts natural enemies of stem-borer and it also prevents striga to attach with the roots of maize. Likewise, the Napier grass attracts the stem-borers which lay their eggs on the leaves. After hatching of these eggs, the Napier grass release a sticky substance which restricts the insect movement thus killing larvae and juveniles of stem-borers (Kuyah *et al.,* 2021).

Seed-enhancements

Seed-enhancement techniques have been widely tested and applied under field conditions, to improve the stand establishment and productivity of crops in diverse soil conditions under optimal and sub-optimal conditions. Seed-priming and seed-coating are important seed-enhancement techniques used worldwide. For example, Rhaman *et al.* (2021) suggested seed-priming with phytohormones as an effective approach to improve abiotic-stress tolerance in crops. Guha *et al.* (2021) suggested nano-priming of rice seeds with zero-valent iron (synthesized from pomegranate peel waste) as a pragmatic approach to enhance rice yield. Positive effects of nano-priming on seedling establishment, seed vigour, growth and economic yield of forage and medicinal plants and increased abiotic stress tolerance owing to nano-priming have been reported (Khalaki *et al.,* 2021). Johnson and Puthur (2021) also reported seed-priming as cost-effective technique for improving salinity tolerance in plants. Several other studies reported that, seed-enhancement techniques such as seed-priming (Table 2) (Nawaz *et al.,* 2016; Farooq *et al.,* 2017; Haider *et al.,* 2020; Ahmad *et al.,* 2021) and seed coating (Javed *et al.,* 2021; Farzaneh *et al.,* 2021) improved the performance of crops and grain biofortification under optimal and sub- optimal and soil environmental conditions.

Table 2. Effects of seed-enhancement techniques on yield improvement in different crops

Country	Crop	Soil type	Study type (pot/field)	Type of seed-enhancement (seed-priming/ seed coating)	Seed-enhancement agent	Application rate with unit	Yield increase (%) over control	References
Pakistan	Rice	Clay loam	Field	Seed-coating	Calcium peroxide	20: 6 (g: mL)	43.9	Javed *et al*. (2021)
Egypt	Maize	Sandy clay	Field	Seed-priming	Sodium chloride	4000 ppm	6.5	El-Sanatawy *et al*. (2021)
Poland	Soybean	Light clay	Field	Seed-priming	Water	0.1 dm^3	20.0	Lewandowska *et al.* (2020)
Pakistan	Wheat	Loamy	Field	Seed-priming	Potassium chloride	2%	7.7	Kashif *et al*. (2021)
Pakistan	Chickpea	Sandy	Field	Seed coating	Zinc	5 mg/kg seed	53.1	Ullah *et al*. (2020)
Serbia	Maize	Calcareous chernozem	Field	Seed-priming	Zinc sulphate	4 mM	16.0	Tamindzic *et al*. (2021)
Pakistan	Mungbean	Sandy loam	Field	Seed-priming	Zinc solution	0.01 M	34.6	Haider *et al*. (2020)
Morocco	Sunflower	Clay silt	Field	Seed-priming	PEG-6000	10%	224.1	Bourioug *et al*. (2020)
Pakistan	Wheat	Sandy clay loam	Field	Seed-priming	Calcium chloride	Ψ S, –1.25 MPa	36.1	Farooq *et al*. (2020)
Pakistan	Wheat	Sandy loam	Pot	Seed coating	Zinc chloride	1.25 g/kgseed	41.0	Rehman and Farooq (2016)

CONCLUSION

Genetics have not driven the post-green revolution crop yield at a steady pace. In this scenario, agronomic innovations have played role to improve yields in farmers' fields with positive impacts on soil and environmental health. Among the most prominent agronomic innovations, use of conservation-agriculture approaches, use of resource-conservation technologies, crop diversification, cereal–legume intercropping, push-pull technology, combination of soil water balance and crop-phenological models, use of controlled and slow-release fertilizer, arbuscular mycorrhizal fungi and rhizobacteria and seed-enhancement techniques have proven successful to boost crop yields and income of farmers. These innovations have provided scientists and farmers a hope to meet future food demands if genetics cannot be able to feed increasing world population.

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