Innovative Agricultural Technologies for Sustainable Food and Environment: A Mini Review

Mohd Danish Ahmad [a], Imran Ahmad[b], Faheem Ahmad[c]

[a,c]Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, India
[b]Malaysia-Japan International Institute of Technology Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
[a]danish_muniri7771@rediffmail.com.com, [b] mustafwibinqamar@gmail.com, [c]faheemahmad9559@gmail.com

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 10 May 2021

Abstract: Agriculture and food systems have high risk of food and nutrition security due to rapid increasing human population and to protect environment from being exploited. Hence, new technologies must be adopted in agricultural system that meet increasing demand of food, reduction in malnutrition and are ecologically sustainable. Enriched plant growth promoting rhizobacteria (PGPR) have proven capabilities for sustainable agricultural techniques and they also reduces the potential threats to soil, water and air environments. PGPR acts as a catalyst to enhance the growth of the plants. The impacts of natural and edaphic parameters like temperature extremities, climate change condition and salinity and the serious threat posed by fertilizers to environment as they release harmful chemicals into air, water, and soil. This led to the advent of environmentally sustainable alternative or biofertilizers. Water management models in agriculture targets to reduce water wastage by determination of accurate water requirement by the crop and to increase the performance of water distribution by adoption of precise irrigation techniques, thus becoming an efficient solution for drylands. Information technology brought a revolution in the agricultural world. Development of mathematical models for crops which hold the dynamic relation between plant, weather conditions, soil, and management operations leading sustainable agriculture, would assist to tackling emerging issues of food security, strategy evaluation and farmer guidance. This paper gives an insight of the innovative technologies in agriculture like culturing of specialized bacteria, alternative fertilizer technologies, inducement of information technology, hopefully it will provide a better projection for sustainable food and agriculture

Keywords: sustainable agriculture, alternative fertilizer, soil bacteria, food security, environment

1. Introduction

World population growth in relation to UN organization will be expected nearly 8.3 and will be 10.9 billion in 2050. The rate of population expansion will lead to increase in food demand from 50% to 75% depending upon the area [1]. Moreover, the worldwide climate conditions will also affect the productivity of food in various parts of the globe. Worldwide climate conditions through the previous century resulted in heat waves because rise of temperature, level of CO_2 in atmosphere, drought spells in some areas and high precipitation in other regions [2]. Changes in climatic conditions and anthropogenic activities have generated high risk to the agricultural sustainability through the depletion of natural resources. Food security is the physical, social and economic requirement of right, safe and nutrient rich food to the human beings at all occasions that can satisfy their dietary needs and food choice for healthy and active life [3]. Globally people suffered from deficiency of nutrition, which was about 821 million in 2017 approximately 10.9% of the world population [4]. Orderly to support the global population, production of food kept stepped by increasing expansion and intensification of agriculture [5, 6]. To meet this target, intensification agricultural systems can support in the improvement of the sustainable agriculture among policy makers, academicians and professionals by increasing awareness to social and environmental issues among stakeholders.

In this scenario, transformation in agricultural systems from traditional to technology, can play an important role to support growing world population and to provide the base for increase in economy and subsequently reduction in poverty. Problem arises that how to increase sustainable production of food to supply as well as provide economic chances for rural and urban groups [7]. There is a great need of institutional help if farmers are to take part into notable sustainability of agricultural production. Agricultural expansion needs intensification in order to meet about the most desired progress into useful sustainable agricultural systems. Various crop simulation models are broadly applied to support this target because they has the capability to measure the complex quantity and non-linear relations between the, pedo-climatic conditions and farmer management [8]. The imbalanced application of traditional fertilizers, pesticides, weedicides, and fungicides has developed an alarming condition by rising pollution in edibles, atmosphere and soil. The future agriculture, particularly in growing nations is under danger because of fast depletion of natural resources mainly the fossil fuel and stock of rock phosphate [9]. The subsequent sections in this review will focus on the technological advancement in the field of agriculture leading to sustainable food and environment, since these technologies will contribute in stabilizing food security throughout the globe without affecting the environment.

2. Microbial Applications towards Sustainable Agriculture

Microbes as Biofertilizers(nutrient mobilizer)

The biofertilizers mainly developed from by various microorganism functions such as nitrogen fixer, phosphate solubilizer and mycorrhizae. Some of them which are most beneficial for biofertilizer producing bacteria are *Bacillus, Pseudomonas, Lactobacillus,* including bacteria responsible for photosynthetic and nitrogen fixation together with *Trichoderma* fungi and yeast. Biofertilizers exhibit high potential for renewable and ecofriendly source of nutrient for plants. They are advantageous being ready to use and containing live formulation of beneficial microorganisms. They enhance the accessibility and benefits of microorganisms when they are applied to seeds, roots and soil by improving health of soil [10].

The biofertilizers possess Nitrogen fixing and Phosphorus solubilizing effects in enhancing crop yield and also play a vital role in soil fertility [11, 12]. Additionally, when they are applied to soil results in improvement of soil structure and reduces the dependency on chemical fertilizers. The use of BGA + *Azospirillum* have shown potentially beneficial in enhancing LAI. Grain yield as well as harvest index increases with application of biofertilizers under low land situations.

Microbes as Plant Growth boosters (Phytostimulators)

There are various bacteria that can enhance growth of plants [13]. Additionally, these bacteria are known as plant-growth promoting rhizobacteria (PGPR). Mechanism of these bacteria is varying in plant growth progress but in general they have significant effect to growth via Phosphorus solubilization, nutrient improvement, or production of plant promoting hormone [14-17]. Bertrand et al [18] investigated that a bacteria (rhizobacterium) belongs to *Achromobacter* genera could enhance length and number of root hair in rapeseed. Prepration of Bio fertiliser is shown in Fig. 1.

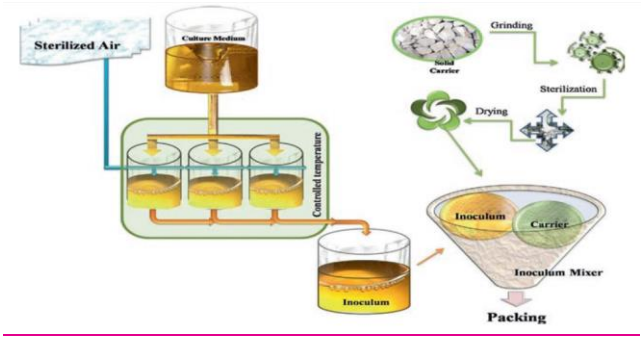

Fig. 1 Preparation of biofertilizer using PGPR [64].

Microbes as Bio Pesticides (Bio Inhibitors)

A modern advent of microbes in the management of plant disease management which can play important role in agricultural system is biocontrol [19-25]. BAU-bio fungicide based on *Trichoderma* has been observed to be effective to control disease in French bean known as root knot [26]. Application of antagonist microbes like *Rhizobium* bacteria and *Bradyrhizobium* bacteria also has influence to control mungbean root knot [27].

3. Alternative Fertilizers and Sustainable Agriculture

Benefits of Alternative Fertilizers to Agriculture and Environment

Alternative fertilizers as compared to traditional fertilizers which are environmental friendly and enhance the use of nutrients efficiently. The technologies of fertilizers with nutrients utilization efficiency and thus reduce loss of nutrients as below [28].

- Modified fertilizers
- Residues of Crops / bio-char
- Bio-fertilizers
- Fertilizers in liquid form

Alternative Fertilizers for Sustainable Agriculture

Crop residues possess great economic importance and are also utilized as fuel and livestock feed material. Therefore sometimes leaving these crops and plant residues in the farm field together becomes organic matter for the soil has potential effect on nutrients and physical condition of soil and biological activity, thus increases

performance of crop because crop residues have excellent capacity of nutrients [29]. Numerous strategies have been employed to repair fertility of soil including conventional application of inorganic fertilizers or utilization of materials for organic fertilizers such as crop residues, green and animal manure [30].

Biofertilizers as an alternative to conventional fertilizer

There are different kinds of plant growth promoting microorganisms (PGPM) such as mycorrhizae, endophytes and phosphorus solubilizing bacteria (PSB). The PGPM play crucial role in the management of fertilizers, which can be summarized as [31].

1. The nutrient management can be done by Rhizosphere microbes
2. Mycorrhizae have advantageous in nutrition of crops
3. Endophytes have been used as an agricultural biofertilizers

4. Sustainable Soil Management

According to the FAO the definition of an International Framework for Evaluating Sustainable Land Management (FESLM) is "*The land management becomes sustainable when it combines the economic values and technologies that influence environment, policies and processes*" [32].

Intensive or conventional agriculture can give rise in degradation of soil properties like physical & chemical, losses of organic matter, minimizes biological activities of soil and thus reduction in the productivity of crop. Conversely the technique of agricultural sustainability anticipate a beneficial and maintaining farming system which depends on three fundamental principles including soil-free agriculture, crop rotation and the surface of soil covered by plant or plant waste [33, 34]. The quality of soil, organic matter and availability of nutrients has proven a potential variation between techniques like as minimum soil tillage or no-tillage and conservational tillage agriculture system. Completely utilized indicators of soil quality in least data sets comprises total organic carbon, pH, volume weight, resistance to aggregate and moisture content [35].

5. Sustainable water Management

Sustainable water management in farming practices target to meet water availability and requirement in quantity and quality, at low cost, space, and time, and without exploiting the environmental wellbeing. Its implementation involves various technological issues like rural communities' social behavior, economic restrictions, framework of institution and agricultural applications. Under water demand management more concentration has been given to irrigation scheduling i.e. when to irrigate and how much water is required have minor role to irrigation systems i.e. how to apply the water in the field. Numerous factors such as stages of crop growth and its water stress sensitivity, climatic situations and water availability to soil decides frequency and time of irrigation. Although, this frequency determines the irrigation technique and consequently, both scheduling of irrigation and the irrigation technique are related to each other [36].

6. Sustainable Nutrient Management

Optimum growth of crop and their yield depends on availability of necessary or some unnecessary crop nutrients like Silicon, Selenium, and Cobalt etc [37]. The attention of nutrients which is found in soil have better crop production that are used by plants. However, physiochemical properties of soil, moisture and microbes found in rhizosphere are significant to the nutrient availability [38]. A bacterium present in rhizosphere called PGPR effectively impact on the nutrient to the plants. Consequently, PGPR applied to root play crucial character for giving profit to the nutrients of soil [39, 40]. Mismanagement or usage in high amount of conventional fertilizers has impact in reducing nutrient in the soil [41, 42]. Conservation tillage and residue management positively enhance quality of soil and its productivity [43]. increasing biotic activities in the soil by supporting organic matter of soil [44].

7. Managing Drylands for Sustainable Agriculture

Globally, the major source that degrades land in drylands is soil erosion [45] and presently it is a major problem [46]. Another major problem of dry lands are loss of soil nutrients due to the wind erosion. In relation to Global Assessment of Soil Degradation (GLASOD) map [47]. Drylands soil degradation are mostly due to wind erosion, proceed by erosion of water, chemical degradation and physical degradation [48]. In drylands agroecosystems, wind erosion is able to balance by adopting suitable farming practices. Some strategies are suggested to control or minimize wind erosion involves: maintaining vegetative cover, establish windbreaks; reduce intensive grazing, use of soil stabilizers, which roughen the surface of soil and reduction in the length of field [49]. Another technological option is conservation tillage which also have significant importance for improving quality of drylands [50, 51]. Dryland areas have highly diverse to crop nutrient management. Nutrient

available in drylands are normally lower than that of optimum in the growing nations, some of nutrients are nitrogen and phosphorus applied in other dryland areas with excess amount [42, 52].

8. Crop-Livestock Interaction Enhancing Sustainable Agricultural Production

Interaction of crop livestock applied into the system of crop livestock production have extremely beneficial and if well managed then it leads towards improvement in the production of sustainable agriculture. Generally, sustainable agricultural production is improved by crop livestock interaction in the following ways:

•Crop livestock interaction enhance efficiently utilization of farm resources by increasing the stability of food crop as well as livestock productivity to satisfy the need of food security to the increasing population.

• It creates space to diversify production, consumption and investment and also helps in the stability of system by reducing risk, increasing employment, hence more people are benefited [53].

• It improves agricultural production by reducing the total production cost such as replacement of chemical fertilizers by the use of manures from livestock, which are too expensive [54].

• High potential environmental risks can be reduced by crop-livestock interaction like as soil erosion, leaching and their impact on the quality of water [53]. It also helps in improving and conserving the production capabilities of soils, by recurring its physical, chemical and biological qualities of soil. Thereby, formulate effective and sustainable agricultural production [54].

9. Information Technology for Sustainable Agriculture

Nowadays, biotechnology supports farming practices, remote sensing, cloud computing and also Internet-of-Things (IoT) [55]. or Internet of Everything (IoE) [56]. IoT concerned about the intelligent relation of farmers or people, things, data and processes. Expansion of IoT manage smart farming and cloud computing by using database of farms or crops such as farm position, size, area of cultivation, time of harvesting and sowing. The emerging trend of IoT devices is shown in Fig. 2 incorporating its marketing.

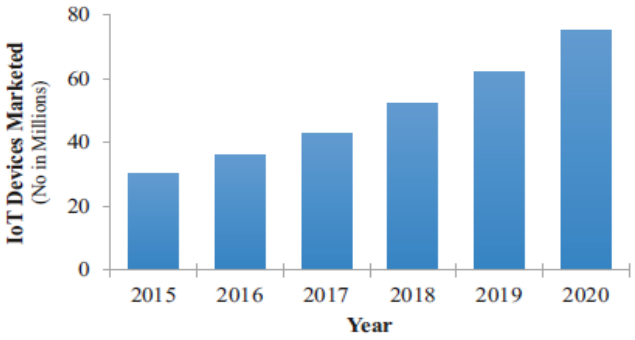

Fig. 2 IoT devices marketed in different countries [65].

The expertize to collect these data in detail is likely to revolutionize agriculture and progress towards efficient and sustainable farming practices. The different sources where data streams coming are satellites, unmanned aerial vehicles, appropriate sensors, and surrounding weather conditions which helps farmers to make timely and quality decision by the development of crop information management system. With the use of smartphone, farmers able to minimize the prediction from their everyday work and select the best option that can be beneficial for their organization and also land sustainability. Employment of artificial intelligence can access new perspective in area of agriculture which results in sustainably producing the quality and sufficient amount of food to overcome food security problem can be reduced by technologies like auto steering and real time agricultural robots. It can enhance in making decisions timely and quality-based to enhance the whole agriculture section of the growing countries.

10. Spatializing Crop Models for Sustainable Agriculture

Globally agriculture challenge has the necessity to improve productivity of crop for the assurance in food security [57], together with achieving sustainability of cropping system [58]. Crop simulation models are being extensively employed to keep this objective due to its ability to express the complicated, non-linear and mutual relation between crop genetics, farmer management and pedo-climatic conditions and thus allowing evaluation of environmental as well as economic performance of the agriculture systems [59]. The main ability of crop simulation modelling is required to recreate the act of target cropping method – intended here as land nexus, atmosphere, and human activities [60]. In order to give a simple depiction of its functioning and reactions to dissimilarities in managing farmer and pedo-atmospheric conditions. Yield gap analysis can be done using with

crop models on various spatial and global scales for food security, land utilization and research of climate alteration [61-63].

11. Concusion

Implementing innovative approaches and technologies to agriculture focuses not only on the increase of the production but also on the ecological sustainability of the production system. This will assist to provide food and other resources to the ever increasing global population and dealing with the constraints which tend to cause hindrance in the efficiency of agriculture like depletion of non-renewable resources, climate change and food insecurity. Usage of bio fertilizers also termed as alternative fertilizers and bio pesticides enhance the growth of crops by supplying essential nutrients without causing any deleterious impact on environment hence leading to productive and sustainable agriculture. As one of the basic functional unit of agriculture, soil sustainability is discussed which elaborates the quality, functionality and health of soil ultimately affecting the sustainability of food and environment. Water provides life to agriculture but at the same time it is very important to use it effectively and efficiently for the irrigation by proper distribution and avoiding its wastage and finding a way out for agriculture in drylands. Better understanding of agroecology will guide the farmer to proportion the nutrient, crops and water in such a way that it will multiply the yield many folds. The application of I.T in agriculture wills not only help farmers to overcome their problems but also help the country to boost overall economy and trade. Especially mobile technology proliferation in rural areas could provide chance to the farmers to improve agricultural productivity. Thus the efficient use of innovative technologies will integrate the productivity and sustainability of the agricultural system and environment.

Acknowledgment

The authors like to thank Aligarh Muslim University and Universiti Teknologi Malaysia for the support provided during the completion of this study. The authors are also grateful to the organizing committee of SURF, 2020 for giving us an opportunity to present our paper in the conference

References

1. Prosekov AY, Ivanova SA (2018) Food security: the challenge of the present. Geoforum 91:73–77 Qi X, Fu Y, Wang RY, Ng CN, Dang H, He Y (2018) Improving the sustainability of agricultural land use: an integrated framework for the conflict between food security and environmental deterioration. Appl Geogr 90:214–223
2. OECD (2016) Agriculture and climate change: towards sustainable, productive and climate-friendly agricultural systems. OECD Meeting of Agriculture Ministers, Background note. Available from: https://www.oecd.org/tad/sustainableagriculture/4_background_note.pdf
3. Food Agriculture Organization (FAO) (2001) The state of food insecurity in the world. Food and Agriculture Organization, Rome
4. Food Agriculture Organization (FAO) (2018) The state of food security and nutrition around the world. Food and Agriculture Organisation of the United Nations (FAO), Rome
5. Food Agriculture Organization (FAO) (2009) High Level Expert Forum – how to feed the world in 2050. Food and Agriculture Organization of the United Nations (FAO), Rome
6. Stevenson JR, Villoria N, Byerlee D, Kelley T, Maredia M (2013) Green revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. Proc Natl Acad Sci 110:8363–8368
7. Ahmad M, Farooq U (2010) The state of food security in Pakistan: future challenges and coping strategies. Pak Dev Rev:903–923
8. Li T, Hasegawa T, Yin X, Zhu Y, Boote K, Adam M, Bregaglio S, Buis S, Confalonieri R, Fumoto T, Gaydon D, Marcaida M III, Nakagawa H, Oriol P, Ruane AC, Ruget F, Singh B, Singh U, Tang L, Tao F, Wilkens P, Yoshida H, Zhang Z, Bouman B (2015) Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions. Glob Change Biol 21:1328–1341
9. Clair SB, Lynch JP (2010) The opening of Pandora's Box: climate change impacts on soil fertility and crop nutrition in developing countries. Plant Soil 335:101–115
10. Ismail EG, Walid WM, Salah K, Fadia ES (2014). Effect of manure and bio-fertilizers on growth, yield, silymarin content, and protein expression profile of Silybum marianum. Adv. Agric. Biol. 1(1):36-44.
11. Kachroo D, Razdan R (2006). Growth, nutrient uptake and yield of wheat (Triticum aestivum) as influenced by biofertilizers and nitrogen. Indian J. Agron. 51(1):37-39.
12. Son TN, Thu VV, Duong VC, Hiraoka H (2007). Effect of organic and bio-fertilizers on soybean and rice cropping system. Japan International Research Center for Agricultural Sciences, Tsukuba, Ibaraki, Japan.
13. Bashan Y, Puente ME, Myrold DD, Toledo G (1998). In vitro transfer of fixed nitrogen from diazotrophic filamentous cyanobacteria to black mangrove seedlings. FEMS Microbiol. Ecol. 26:165-170.

14. Bashan Y, Harrison SK, Whitmoyer RE (1990). Enhanced growth of wheat and soybean plant inoculated with Azopirillum brasilense is not necessary due to general enhancement of mineral uptake. Appl. Environ. Microbiol. 56:769-775.
15. Okon Y, Labandera-Gonzalez CA (1994). Agronomic applications of Azospirillum: An evaluation of 20 years worldwide field inoculation.Soil Biol. Biochem. 26:1591-1601.
16. Goldstein AH, Braverman K, Osorio N (1999). Evidence for mutualism between a plant growing in a phosphate-limited desert environmentand a mineral phosphate solubilizing (MPS) rhizobacterium. FEMS Microbiol. Ecol. 30:295-300.
17. Richardson AE (2001). Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. Aust. J. Plant Physiol. 28:897-906.
18. Bertrand H, Plassard C, Pinochet X, Touraine B, Normand P, Cleyet- Marel JC (2000). Stimulation of the ionic transport system in Brassica napus by a plant growth-promoting rhizobacterium (Achromobacter sp.). Can. J. Microbiol. 46:229-236.
19. Tverdyukev AP, Nikonov PV, Yuslichenko NP. (1994). Trichoderma. Rev. P1. Pathology 73 (4): 237.
20. Hoffmann-Hergarten S, Gulati MK, Sikora RA (1998). Yield response and biological control of Meloidogyne incognita on lettuce and tomato with rhizobacteria. Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz 105(4):349-358.
21. Yang-Xiu Juan, He-Yuxian, Chen-Furu, Zhengliang (2000). Isolation and selection of eggmasses of Meloidogyne spp. in Fujiana province. Fujiana J. Agric. Sci. 15(1):12-15.
22. Sharon E, Bar EM, Chet I, Herrera EA, Kleifeld O, Spiegel Y (2001). Biological control of the root-knot nematode Meloidogyne javanica by Trichoderma harzianum. Phytopathology 91(7):687-963.
23. Senthilkumar T, Rajendran G (2004). Bio-control agents for the management of disease complex involving root-knot nematode, Meloidogyne incognita and Fusarium moniliforme on grapevine (Vitis vinifera). Indian J. Nematol. 34(1):49-51.
24. Li-Bin, Xie-Guanlin, Soad A, Goosemans J. (2005). Suppression of Meloidogyne javanica by antagonistic and plant growth promoting rhizobacteria. J. Zhejiang Univ. Sci. 6B (6):496-501.
25. Hossain MA, Mahbub M, Khanam N, Hossain MS, Islam MM (2009). Effect of Bio-agents on growth and root-knot (Meloidogyne javanica) disease of soybean. J. Agrofor. Environ. 3(1):77-80.
26. Rahman M (2005). Effect of BAU-Biofungicide and nematicide Curaterr against root-knot of French bean. M.Sc. Thesis, Department of Plant Pathology, Bangladesh Agricultural University, Mymensingh.
27. Khan A, Zaki MJ, Tariq M (2006). Seed treatment with nematicidal Rhizobium species for the suppression of Meloidogyne javanica root infection on mungbean. Int. J. Biol. Biotechnol. 3(3):575-578.
28. Abbas A, Yaseen M, Khalid M, Naveed M, Aziz MZ, Hamid Y, Saleem M (2017) Effect of biochar-amended urea on nitrogen economy of soil for improving the growth and yield of wheat (Triticum Aestivum L.) under field condition. J Plant Nutr 40(16):2303–2311
29. Azam F (1990) Comparative effect of organic and inorganic nitrogen sources applied to a flooded soil on rice yield and availability of Nitrogen. Plant Soil 125:255–263
30. Issaka RN, Buri MM, Tobita S, Nakamura S, and Owusu-Adjei E 2012: Indigenous fertilizing materials to enhance soil productivity in Ghana. In Soil fertility improvement and integrated nutrient management-A global perspective, Walen JK (ed.) In-Tech. ISBN 978-953-307 945-5, 119-134.
31. Nadeem SM, Ahmad M, Zahir ZA, Javaid A, Ashraf M (2014) The role of mycorrhizae and plant growth promoting rhizobacteria (PGPR) in improving crop productivity under stressful environments. Biotechnol Adv 32(2):429–448
32. FAO. FESLM: An International Framework for Evaluating Sustainable Land Management. World Soil Resources Report 73. 1993. Available from:http://www.fao.org/3/T1079E/t1079e04.htm#nature%20of%20sustainable%20 land%20management%20(slm)
33. [Accessed: 05 June 2019]
34. Giller KE, Andersson JA, Corbeels M, Kirkegaard J, Mortensen D, Erenstein O, et al. Beyond conservation agriculture. Frontiers in Plant Science. 2015;6:870. DOI: 10.3389/fpls.2015.00870
35. Pittelkow CM, Liang X, Linquist BA, van Groenigen KJ, Lee J, Lundy ME, et al. Productivity limits and potentials of the principles of conservation agriculture. Nature. 2015;517:365-368. DOI: 10. 1038/nature13809
36. Bayram M, Günal H, Özgöz E. Importance of soil quality in determination of sustainable soil tillage methods. Yuzuncu Yil University Journal of Agricultural Sciences. 2015;25(3):337-346
37. Chartzoulakisa and Bertaki, (2015) The Effects of Irrigation and Drainage on Rural and Urban Landscapes, Patras, Greece Sustainable water management in agriculture under climate change. Agriculture and Agricultural Science Procedia 4, IRLA2014, pp 88 – 98
38. Dimkpa C, Bindraban P, McLean JE, Gatere L, Singh U, Hellums D (2017) Methods for rapid testing of plant and soil nutrients. In: Sustainable agriculture reviews. Springer, Cham, pp 1–43
39. Marschner P (2012) Marschner's mineral nutrition of higher plants, 3rd edn. Academic, London

40. Robinson D, Griffiths B, Ritz K, Wheatley R (1989) Root-induced nitrogen mineralisation: a theoretical analysis. Plant and Soil 117(2): 185–193
41. Nadeem SM, Ahmad M, Zahir ZA, Javaid A, Ashraf M (2014) The role of mycorrhizae and plant growth promoting rhizobacteria (PGPR) in improving crop productivity under stressful environments. Biotechnol Adv 32(2):429–448
42. Zhu ZL, Chen DL (2002) Nitrogen fertilizer use in China-contributions to food production, impacts on the environment and best management strategies. Nutr Cycl Agroecosyst 63:117–127
43. Ju XT, Xing GX, Chen XP, Zhang SL, Zhang LJ, Liu XJ, Cui ZL, Yin B, Christie P, Zhu ZL, Zhang FS (2009) Reducing environmental risk by improving N management in intensive Chinese agricultural systems. Proc Natl Acad Sci USA 106:3041–3046
44. Paul BK, Vanlauwe B, Ayuke F, Gassner A, Hoogmoed M, Hurisso TT, Koala S, Lelei D, Ndabamenye T, Six J, Pulleman MM (2013) Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. Agric Ecosyst Environ 164:14–22
45. Dungait JAJ, Hopkins DW, Gregory AS, Whitmore AP (2012) Soil organic matter turnover is governed by accessibility not recalcitrance. Glob Chang Biol 18:1781–1796
46. Farooq M, Siddique KHM (2016) Research and developmental issues in dryland agriculture. In:Farooq M, Siddique KHM (eds) Innovations in dryland agriculture. Springer International Publishing AG, Cham, pp 31–46
47. Plaza-Bonilla D, Arrúe JL, Cantero-Martínez C, Fanlo R, Iglesias A, Álvaro-Fuentes J (2015) Carbon management in dryland agricultural systems. A review. Agron Sustain Dev 35:1319–1334
48. Oldeman LR (1994) The global extent of soil degradation. In: Greenland DJ, Szabolcs I (eds) Soil resilience and sustainable land use. CAB International, Wallingford
49. Sterk G, Riksen M, Goossens D (2001) Dryland degradation by wind erosion and its control. Ann Arid Zone 40:351–367
50. Blanco H, Lal R (2008) Principles of soil conservation and management. Springer, Heidelberg
51. Cantero-Martínez C, Angás P, Lampurlanés J (2007) Long-term yield and water use efficiency under various tillage systems in Mediterranean rainfed conditions. Ann Appl Biol 150:293–305
52. Lampurlanés J, Plaza-Bonilla D, Álvaro-Fuentes J, Cantero-Martínez C (2016) Long-term analysis of soil water conservation and crop yield under different tillage systems in Mediterranean conditions. Field Crops Res 189:59–67
53. Nawaz A, Farooq M (2016) Nutrient management in dryland agriculture systems. In: Farooq M, Siddique KHM (eds) Innovations in dryland agriculture. Springer International Publishing AG, Cham, pp 115–142
54. Jabbar MA, Cobbina J (1990) Crop-livestock interaction for sustainable food crop production in tropical Africa. Summary of a lecture delivered at the training course on sustainable food production systems in Tropical Africa, held at IITA, Ibadan, 18 June–6 July 1990
55. Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C (1999) Livestock to 2020: the next food revolution, Food, agriculture and the environment discussion paper 28. International Food Policy Research Institute, Washington, DC
56. Li Y (2018) Problems of application of internet of things in agricultural informationization and recommendations for Shandong Province. Asian Agric Res 10(2):51–54
57. Dey S, Saha JK, Karmakar NC (2015) Smart sensing: chipless RFID solutions for the Internet of everything. IEEE Microw Mag 16(10):26–39
58. Ray DK, Mueller ND, West PC, Foley JA (2013) Yield trends are insufficient to double global crop production by 2050. PLoS ONE 8:e66428
59. Ramankutti N, Mehrabi Z, Waha K, Jarvis L, Kremen C, Herrero M, Rieseberg LH (2018) Trends in global agricultural land use: implications for environmental health and food security. Ann Rev Plant Biol 69:789–815
60. Li T, Hasegawa T, Yin X, Zhu Y, Boote K, Adam M, Bregaglio S, Buis S, Confalonieri R, Fumoto T, Gaydon D, Marcaida M III, Nakagawa H, Oriol P, Ruane AC, Ruget F, Singh B, Singh U, Tang L, Tao F, Wilkens P, Yoshida H, Zhang Z, Bouman B (2015) Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions. Glob Change Biol 21:1328–1341
61. Malek K, Stockle C, Chinnayakanahalli K, Nelson R, Liu M, Rajagopalan K, Barik M, Adam JC (2017) VIC–CropSyst-v2: a regional scale modeling platform to simulate the nexus of climate, hydrology, cropping systems, and human decisions. Geosci Model Dev 10:3059–3084
62. Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012) Closing yield gaps through nutrient and water management. Nature 490(7419):254–257
63. Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N (2014) A meta-analysis of crop yield under climate change and adaptation. Nat Clim Change 4(4):287–291
64. Asseng S, Ewert F, Martre P, Rotter RP, Lobell DB, Cammarano D, Kimball BA, Ottman MJ, Wall GW, White JW, Reynolds MP, Alderman PD, Prasad PVV, Aggarwal PK, Anothai J, Basso B, Biernath C, Challinor AJ, De Sanctis G, Doltra J, Fereres E, Garcia-Vila M, Gayler S, Hoogenboom G, Hunt LA,

Izaurralde RC, Jabloun M, Jones CD, Kersebaum KC, Koehler AK, Muller C, Naresh Kumar S, Nendel C, O'Leary G, Olesen JE, Palosuo T, Priesack E, Eyshi Rezaei E, Ruane AC, Semenov MA, Shcherbak I, Stockle C, Stratonovitch P, Streck T, Supit I, Tao F, Thorburn PJ, Waha K, Wang E, Wallach D, Wolf J, Zhao Z, Zhu Y (2015) Rising temperatures reduce global wheat production. Nat Clim Change 5(2):143–147

65. Tabassum B, Khan A, Tariq M, Ramzan M, Khan MSI, Shahid N, Aaliya K (2017) Bottlenecks in commercialization and future prospects of PGPR. Appl Soil Ecol 121:102–117
66. Business Insider (BI) Intelligence (2015). The internet of things: examining how the IoT will affect the world, Technical report. Business Insider, New York. November 2015.