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Review Article

Rice Production Systems in Pakistan: An Overview

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ABSTRACT

Rice is the major crop of more than 100 countries and production systems of rice have been classified into various groups depending on the context over years. In this Review, an attempt has been made to describe the production systems of rice widely used across the globe. Rice production systems are classified as (a) transplanted rice (TPR) production systems and (b) direct-seeded rice (DSR) production systems on the basis of different methods of world rice production. DSR production systems are also classified as (i) production system for dry-seeded rice (dry-DSR), (ii) production system for wet-seeded rice (wet-DSR) and (iii) production system for water-seeded rice (water-DSR). When the best management practices are used, TPR and DSR efficiency is stated to be comparable. This review contains information on rice production systems as well as recommend potential research needs for rising the productivity in rice production systems in order to meet future food demands.

Keywords: *Rice Production Systems; Direct Seeded System; Traditional Production System; Dry-Seeded Rice; Wet-Seeded Rice*

INTRODUCTION

Rice is most important cereal crop (Chadhar et al., 2020) and primary food commodity for over 50% world's population (Islam et al., 2010). Scientifically rice is known as *Oryza sativa* (L.) and belongs to family poaceae. Pakistan is considered as the largest rice producing country and big exporter of basmati rice in the whole world. Only rice cultivation provides a big contribution in foreign exchange earning of country and provides employment to local community.

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Rice production of Pakistan reached around 7.5 million tons and it is cultivated on 2.6 m ha area. In 2017-2018, Pakistan gained $1.677 billion from exports of rice and 0.6% of national GDP and 3.1% of value-added services. Area under rice cultivation was 2793 thousand hectares with overall production of 7.442 m tons (Govt. of Pakistan, 2018). Rice is composed of water, starch, protein (with essential amino acids) with 12%, 75-80% and 7.5% of contents respectively. Digestibility and biological value of rice protein is excellent with 92% and 74% respectively. Agricultural productions are facing a major challenge to fulfil the requirements of growing population and many poor countries are facing problem of malnutrition (Adnan et al., 2020; Saeed et al., 2020). The food demand throughout the world is increasing because of rising human population (Kalsoom et al., 2020). Mineral elements like magnesium (Mg), calcium (Ca) and phosphorus (P), then traces of micro elements such as zinc (Zn), manganese (Mn), iron (Fe) and copper (Cu) are present in rice (Verma and Srivastav, 2017). Around the globe, over 160-million-hectare area is cultivated for fine and coarse rice production. This area ranks 11 percent region from cultivated and gives more than 7 hundred million tonnes of rice. Rice is mostly cultivated in all types of soils except sandy soils and then areas where rice-wheat cropping pattern is followed. In Asia, rice wheat cropping pattern is to be followed on 24 m ha of land while on 13.5 m ha area in South Asia (Hobbs and Gupta, 2003). Currently, there is a need for agricultural production, not only to fulfil high quality requirements, but also to make strategies that are environmentally sustainable (Ilahi et al., 2021). Rice is cultivated by two methods i.e. by raising nursery it is common and conventional techniques of growing rice and other is direct seeding method, this is the latest technique for growing rice and is common now a day. In conventional method, raised nursery is transplanted into puddled soil. This method requires large amount of water (Bouman et al., 2007) high cost and labour-intensive cultivation technique (Ehsanullah et al., 2007; Kamboj et al., 2013). In lowland rainfed and irrigated areas puddled transplantation of is the most common method because of high amount of water accessibility (Singh et al., 2008). Usually, in puddled transplanted germination of seeds in nursery occurs within two to three weeks and then nurseries are transplanted mechanically or manually into puddled fields. Direct seeded rice grows at slower rate as we relate it with transplanting rice (Farooq et al., 2011). The modern rice cultivation method is direct sowing of dry seed into the field. In DSR method rice seed are sown directly with the help of seed drill or broadcast method is also observed in many experiences. This method saves labour, time and expenses as compared to puddled transplanted system (Jabran et al., 2012). Globally, farmers are accepting DSR method due to low cost of production (Rao et al., 2007). In world, 3rd part of the total paddy produce is produced through DSR method. DSR requires less manpower, irrigation water and other inputs without affecting yield. DSR method is also competent in weed eradication and water management techniques (Sudhir et al., 2011; Liu et al., 2015; Tao et al., 2016). In DSR production system, seeds are sown directly on superficial surface and these seeds are planted in rain fed, irrigated and deep-water systems (Ishfaq et al., 2018). Manually and mechanically seeds can be sown. For rice productions, various elements control the production and area. These include changing climate conditions throughout the season, less availability of finance, low availability of surface water and not stipulation of good price through the government for purchase from farmers. DSR system has the probability for achieving higher water efficiency and eradicating the edaphic dispute in the rice-wheat cropping technique (Khaliq et al., 2012). The core aim of this review is to describe the rice production systems (traditional production system and direct seeded system) and compare both methods of cultivation.

Rice Production Systems

Rice production is facing various difficulties including extreme climatic changes, high cost of production and water shortage in rice producing regions are massive dangers to declining yield of rice. McLean et al. (2002) stated that rice has primary position as cereal crop and staple food crop for local community of Pakistan. Rice can provide and fulfilled the energy and protein requirement for human body. Basically, there are two production systems are famous for rice production i.e. Puddled transplanting of rice is conventional method for rice production while direct seeded of rice is latest method for rice production. Environmental and socio-economic factors highly influence the production system for rice. In conventional method for rice production, it includes raising of nursery and then transplanting it into flooded fields (Zulfiqar et al., 2020). In recent days, agriculture sector is facing severe challenges associated with shortage of water. To address these challenges, different methods are developed for conserving the water proficiently (Kahlown et al., 2002). In South Asia, puddled method for cultivation of paddy is followed mostly in rice-wheat cropping pattern areas (Hobs and Gupta, 2003). Rice production in Pakistan remained at average 2.42t per hectare throughout 2017-18 which is outlying under potential. It is reported that puddled production of rice will experience the severe effect of physical or economical water shortfall till 2025 in Asia. Huge water is needed for production of rice by puddled transplanted method (Hobs and Gupta 2003). Basmati rice is produced more in many regions of Punjab province because of suitable environmental and soil conditions. It is demand of today world to transfer on to latest production novelties, improve rice farming research, soil protection and concise use of ground water (Abedullah and Mushtaq, 2007). Weak seedling establishment and uncontrolled weeds are the main problems in direct seeded rice. Seed priming before sowing into field is the best way to overcome seedling establishment problem in DSR. In many research experiments on rice, it was concluded that due to seed priming rice plants have improved their growth and agronomic characteristics all through the life cycle (Farooq et al., 2006).

Traditional production system

Globally, it is reported that three fourths of rice are cultivated by traditional puddled transplanting method. In this method, rice nursery is raised and then its seedlings are transplanted into flooded field (Bouman et al., 2007). Trained labour required for raising the nursery and transplanting of seedlings of rice crop (Farooq et al., 2001). Puddled condition of rice field is maintained up by applying uniform quantity of irrigation and mechanical operations in the soil. For traditional production system, it is calculated that about 3500-4500 L of irrigation water utilized for production 1 kg of rice and it is three times higher than other cereals (Joshi et al., 2013). At earlier stages after transplanting of rice nursery, a constant water level should be maintained which helps in proper crop establishment and effective weeds control (Singh et al., 2001). In conventional method, loss of water has been observed by the formation of hard pan to reduce water losses through escape (Farooq et al., 2009). In rice production systems, emissions of carbon dioxide (CO_2), methane (CH_4), and N_2O gases to the atmosphere have big contribution to global climate change (Ali et al., 2019). In transplanted rice fields emission of greenhouse gases (GHG) has been observed which give rise to global temperature (Khalil and Aslam, 2009). These gases are produced as a result of anaerobic degradation of organic matter (OM) present below the soil layers. Methane is produced after the decay OM and it is the chief product of this decomposition (Hodges, 2010). The GHG are the main cause of global warming which increase the temperature (Robinson et al., 2007). A move from conventional method of rice method to direct seeded method in aerobic condition may reduce in production of GHG (Wassmann et al., 2004). Moreover, overall profits have been reduced in conventional rice production

method due to hike in labour costs and production material input costs (Velasco and Pandey, 1998). Chauhan et al. (2015) stated that due to advanced weed control gives better yield in conventional method and DSR method is ideal by sufficient irrigation water and low labour cost. Chauhan and Opeña (2012) reported that puddled environment in traditional rice production consumes up to 30% of the overall rice water requirement. Although, flooded method is more suitable in rice-wheat cropping system, as it decreases soil permeability by forming hardpan and decline water losses by percolation. Conversely, continuous puddling practice influence the production and yield of subsequent non-rice highland crops in rotations (McDonald et al. 2006) by formation of soil aggregates, decreasing penetrability for roots in underground layers and constituting hardpan at depths (Sharma et al., 2003).

Direct seeded system

In DSR production system, rice seeds are sown directly in the field in aerobic environment (Farooq et al., 2011). For this sowing method no flooded or puddling environment is required for paddy production, but irrigation water is applied according to requirement and environment of the crop (Bouman and Tuong, 2001). DSR method saves both time and labour as well (Kumar and Ladha, 2011). This method also intended to minimise utilization of H_2O for rice cultivation with no compromise on production (Cabangon et al., 2012; Predeepa, 2012). A move from puddled transplanted production method of rice to direct seeded rice production method saves water significantly. DSR method can decreases water needs up to half of actual uses in PTR method; by decreasing evaporation, percolation and seepage losses during irrigation (Chandra and Sirisha, 2019). Water use efficiency is observed higher in DSR method as likened with PTR. This WUE is due to of application of less irrigation water in DSR as in PTR one third of the water is required for formation of puddled conditions. But in DSR as such no requirement is needed. In DSR production system water is applied after observing the field and environmental conditions (Bhushan et al., 2007). DSR production method enhances adoptability of wheat-rice cropping pattern by settling soil problems among rice and successive winter season crops. DSR is ready to harvest crop as seven to fifteen days prior to PTR (Hussain et al., 2012) which reliefs farming community to sow wheat at suitable time (Ladha et al., 2003). Hence, problems of wheat delay cultivation are settled by following DSR production system (Pathak et al., 2011). Biomass production is higher in direct sowing production system than the PTR production system (Naklang et al., 1996). Ehsanullah et al. (2000) stated that DSR production system have less yield as compared with the PTR system It has been also reported that we can saves time, reduced cost and labour and can get maximum similar yield of PTR by adopting proper production practices in DSR method (Pathak et al., 2011; Joshi et al., 2013). Naresh et al. (2013) stated that direct sowing is a valuable technique for paddy production because it decreases cost of cultivation and reduce the time span of crop cultivation by aligning the yield loss. Globally, DSR production system is adapted by farming community. Rao et al., (2007) stated that one fourth production of paddy is through direct seeded method. Tao et al., (2016) stated that proper weeds control and management of water in DSR method significantly reduced the labour demand without disturbing the yield production. Zhu, (2008) reported that in dry DSR production system kernel yield has been improved by 22 % and reduced the water input by 6000 m^3 ha^{-1} relative to TPR production system. In DSR production system 35-57% of water saving observed into aerobic soil conditions as related with PTR method (Farooq et al., 2009b). Kumar and Ladha, (2011) stated that DSR not only saves the water and labour but it also lessens emission of methane in rice, reduce of costs of farming and permits planting in time of successor crop. Now it is ordinary that water and labour costs will increase in the near future and management practices and registered varieties

availing in DS system looking more attractive to farmers.

Transplanted vs direct seeded rice

Transplanting of rice is most common practice adapted in South Asia. Environmental problems such as soil issues and climatic issues and higher labour costs, demands much changes in the transplanting system. Accuracy of distance in rows and plants is cannot be maintained, it is the reason for the low yield in rice. Recommended plant and row distancing is maintained for getting the higher yields in rice (Baloch et al., 2002). In transplanting rice, recommended plants population is maintained, and it also requires a lot of labour. This labour and cost requiring transplanting technique can be replaced by DSR method (Alam et al., 2018). High weeds emergence is the biggest drawback in DSR production system. These weeds successfully have been controlled using pre and post-emergence herbicides in DSR production system without disturbing paddy yield (Mann et al., 2007; Bhurer et al., 2013). Mubeen et al. (2014) also described that use of post-herbicides as compared to manual weed removal resulted in the highest paddy yield in DSR system. Beltran et al. (2012) described that it is not economical to remove weeds manually in paddy fields. Ehsanullah et al., (2000) stated that due to higher yield of paddy, the PTR system for rice production is better than the DSR system, and the higher yield of paddy is related to tiller formation, kernel weight and maximum harvest index. However, globally rice production area is declining, to increase the paddy yield the only possible way to increase production per unit area (Balmford et al., 2018). The sustainability of rice ecosystems, increasing production as population grow, reducing water supply and expensive labor are major problems of rice cultivation (Pathak et al., 2011). DSR is alternative production systems provides a smaller amount for labor and demands reduced water supply for paddy production (Kumar et al., 2016). In addition, the results of Farooq and Basra (2008) showed that in the rice field compaction and bulk density of the soil increased during the operation in puddled water compared to the soil prepared in DSR method. This edaphic change conflicts and affects subsequent rabi season crops. Therefore, soil conflicts can be settled with the help of DSR method, some controlling measures must have been implemented to achieve higher paddy production as compared to PTR method (Joshi et al., 2013).

CONCLUSION

As in the developed countries, there is a change in adoption of DSR production systems due to the benefits of DSR production systems, such as lower production costs, improved productivity of resource usage (water, labor, and energy) and revenue compared to TPR. There is a need for active research activities to understand the emerging rice production systems around the world and to establish realistic integrated crop management strategies that efficiently, sustainably and economically boost rice productivity and production with a minimal environmental footprint.

REFERENCES

Abedullah, S. K., & Mushtaq, K. (2007). Analysis of technical efficiency of rice production in Punjab (Pakistan). *Pak. Econ. Soc. Rev.* 45(2), 231–244.

Adnan, M., Asif, M., Bilal, H. M., Rehman, B., Adnan, M., Ahmad, T., Rehman, H. A., & Anjum, M. Z. (2020). Organic and inorganic fertilizer; integral part for crop production. *EC Agri. 6*(3), 01-07.

Alam, M. J., Humphreys, E., Sarkar, M. A. R., & Sudhir-Yadav. (2018). Comparison of dry seeded and puddled transplanted rainy season rice on the High Ganges River Floodplain of Bangladesh. *Eur. J. Agron.* 96, 120–130.

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., Field, R., Garnsworthy, P., Green, R., Smith, P., & Waters, H. (2018). The environmental costs and benefits of high-yield farming. *Nature Sustain*. 1(9), 477–485.

Baloch, A. W., Soomro, A. M., Javed, M. A., Ahmed, M., Bughio, H. R., Bughio, M. S., & Mastoi, N. N. (2001). Optimum Plant Density for High Yield in Rice (*Oryza sativa* L.). *Asian J. Plant Sci. 1*(1), 25–27.

Beltran, J. C., Pannell, D. J., & Doole, G. J. (2012). Economic implications of herbicide resistance and high labour costs for management of annual barnyardgrass (*Echinochloa crus-galli*) in Philippine rice farming systems. *Crop Prot.* 31(1), 31–39.

Bhurer, K., Yadav, D., Ladha, J., Thapa, R., & Pandey, K. (2013). Effect of integrated weed management practices on performance of dry direct seeded rice (*Oryza sativa* L.). *Agron. J. Nepal.* 3, 53–63.

Bhushan, L., Ladha, J. K., Gupta, R. K., Singh, S., Tirol-Padre, A., Saharawat, Y. S., M. Gathala & Pathak, H. (2007). Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. *Agron. J. 99*(5), 1288-1296.

Bouman, B. A. M. R.M. Lampayan & T.P. Toung. (2007). Water management in irrigated rice: coping with water scarcity. International Rice Research Institute, Los Baños, Philippines.

Cabangon, R., Lampayan, R., Bouman, B., & Tuong, T. P. (2012). Water saving technologies for rice production in the Asian region. In *Extension Bulletin - Food & Fertilizer Technology Center* (Issue No.648, p. unpaginated). Food and Fertilizer Technology Center for the Asian and Pacific Region. http://www.agnet.org

Chadhar, A. R., Nadeem, M. A., Ali, H. H., Safdar, M. E., Raza, A., Adnan, M., Ali, L., Kashif, S & Javaid, M. M. (2020). Quantifying the Impact of Plant Spacing and Critical Weed Competition Period on Fine Rice Production under the System of Rice Intensification. *Int. J. Agri. Biol. 24*(5), 1142-1148.

Chandra, M. S., & Sirisha, L. (2019). More Rice, Less Water-Precision Water Management Approaches for Increasing Water Productivity in Irrigated Rice-Based Systems under North IGP: A Review. *Int. J. Curr. Microbiol. App. Sci*. *8*(5), 1727-1747.

Chauhan, B. S., & Opeña, J. (2012). Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. *Field Crop. Res. 137*, 56-69.

Chauhan, B. S., Awan, T. H., Abugho, S. B., & Evengelista, G. (2015). Effect of crop establishment methods and weed control treatments on weed management, and rice yield. *Field Crop. Res. 172*, 72-84.

Ehsanullah, Akbar, N., Jabran, K., & Habib, T. (2007). Comparison of different planting methods for optimization of plant population of fine rice (*Oryza sativa* L.) in Punjab (Pakistan). *Pak. J. Agri. Sci. 44*(4), 597–599.

Ehsanullah, Iqbal, I., Ahmad, A., & Randhawa, S. A. (2000). Effect of Direct Seeding and Transplanting Methods on the Yield and Quality of Fine Rice Basmati-370. *Int. J. Agri. Biol. 2*(3), 251.

Farooq, M., & Basra, S. M. (2008). Resolving the edaphic conflict in rice–wheat system. In *Proceedings of the 14th Australian Agronomy Conference. Global Issues Paddock Action, September, Adelaide, South Australia*.

Farooq, M., Barsa, S. M., & Wahid, A. (2006). Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. *Plant growth regul. 49*(2), 285-294.

Farooq, M., Kobayashi, N., Wahid, A., Ito, O., & Basra, S. M. (2009). 6 Strategies for Producing More Rice with Less Water. *Adv. Agron. 101*(4), 351-388.

Farooq, M., Siddique, K. H., Rehman, H., Aziz, T., Lee, D. J., & Wahid, A. (2011). Rice direct seeding: experiences, challenges and

opportunities. *Soil Till. Res. 111*(2), 87-98.

Farooq, M., Wahid, A., & Siddique, K. H. (2012). Micronutrient application through seed treatments: a review. *J. Soil Sci. Plant Nutr. 12*(1), 125-142.

Farooq, U., Sheikh, A. D., Iqbal, M., Bashir, A., & Anwar, Z. (2001). Diffusion possibilities of mechanical rice transplanters. *Int. J. Agri. Bio. 3*(1), 17-20.

Govt. of Pakistan, 2018. Economic Survey of Pakisan 2017-18. Ministry of Finance, Economic Advisor's Wing, Islamabad, Pakistan.

Hobbs, P. R., & Gupta, R. K. (2003). Rice-wheat cropping systems in the Indo-Gangetic plains: issues of water productivity in relation to new resource-conserving technologies. *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, 239–253.

Hodges, S. C. (2010). Soil fertility basics. *Soil Science Extension, North Carolina State University*.

Hussain, S., Maqsood, M. A., Rengel, Z., & Aziz, T. (2012). Biofortification and estimated human bioavailability of zinc in wheat grains as influenced by methods of zinc application. *Plant Soil. 361*(1), 279-290.

Ilahi, H., Hidayat, K., Adnan, M., Rehman, F. ur, Tahir, R., Saeed, M. S., Shah, S. W. A., & Toor, M. D. (2021). Accentuating the Impact of Inorganic and Organic Fertilizers on Agriculture Crop Production: A Review, *Ind. J. Pure App. Biosci. 9*(1), 36-45. DOI: http://dx.doi.org/10.18782/2582-2845.8546.

Ishfaq, M., Akbar, N., Khan, I., Anjum, S. A., Zulfiqar, U., Ahmad, M., Ahmad, M., & Chattha, M. U. (2018). Optimizing Row Spacing for Direct Seeded Aerobic Rice under Dry and Moist Fields. Pak. J. Agri. Res 31(4).

Islam, M. S., Peng, S., Visperas, R. M., Bhuiya, M. S. U., Hossain, S. A., & Julfiquar, A. W. (2010). Comparative study on yield and yield attributes of hybrid, inbred, and NPT rice genotypes in a tropical irrigated ecosystem. *Bangladesh J. Agri. Res*. *35*(2), 343-353.

Jabran, K., Farooq, M., Hussain, M., Khan, M. B., Shahid, M., & Dong-Jin, L. (2012). Efficient weeds control with penoxsulam application ensures higher productivity and economic returns of direct seeded rice. *Int. J. Agri. Biol. 14*(6), 901-907

Joshi, E., Kumar, D., Lal, B., Nepalia, V., Gautam, P., & Vyas, A. K. (2013). Management of direct seeded rice for enhanced resource-use efficiency. *Plant Knowledge J. 2*(3), 119-134.

Kahlown, M. A., Gill, M. A., & Ashraf, M. (2002). *Evaluation of resource conservation technologies in rice, wheat system of Pakistan*. Pakistan Council of Research in Water Resources, Islamabad, Pakistan.

Kalsoom, M., Rehman, F. U., Shafique, T., Junaid, S., Khalid, N., Adnan, M., & Ali, H. (2020). Biological Importance of Microbes in Agriculture, Food and Pharmaceutical Industry: A review. *Innovare J. Life Sci. 8*(6), 1-4. DOI: https://doi.org/10.22159/ijls.2020.v8i6.39845.

Kamboj, B. R., Yadav, D. B., Yadav, A. K., Goel, N. K., Gill, G., Malik, R. K., & Chauhan, B. S. (2013). Mechanized transplanting of rice (*Oryza sativa* L.) in nonpuddled and no-till conditions in the rice-wheat cropping system in Haryana, India. *Am. J. Plant Sci.* 4:2409-2413.

Khalil, K., & Aslam, M. (2009). *Emissions Of Greenhouse Gases From Rice Agriculture* (No. DOE/ER/63913-1). Portland State University, Portland, Oregon.

Khaliq, A., Matloob, A., Ahmad, N., Rasul, F., & Awan, I. U. (2012). Post emergence chemical weed control in direct seeded

fine rice. *J. Ani. Plant Sci. 22*(4), 1101-1106.

Kumar, R., Kumawat, N., Kumar, S., Kumar, R., Kumar, M., Sah, R. P., Kumar, U & Kumar, A. (2016). Direct seeded rice: research strategies and opportunities for water and weed management. *Oryza Int. J. Rice. 53*(4), 354-365.

Kumar, V., & Ladha, J. K. (2011). Direct seeding of rice: recent developments and future research needs. *Advances in agronomy*, *111*, 297-413.

Ladha, J. K., Pathak, H., Tirol-Padre, A., Dawe, D., & Gupta, R. K. (2003). Productivity trends in intensive rice-wheat cropping systems in Asia. In *Improving the productivity and sustainability of rice-wheat systems: issues and impacts. Proceedings of an international symposium, held at the 2001 Annual Meetings of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Charlotte, NC, USA, 22 October 2001* (pp. 45–76). American Society of Agronomy.

Liu, H., Hussain, S., Zheng, M., Peng, S., Huang, J., Cui, K., & Nie, L. (2015). Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. *Agron. Sustain. Dev. 35*(1), 285-294.

Lun, Z. H. U. (2008). A report on dry direct seeding cultivation technique of early rice. *J. Guangxi Agri. 23*, *10-11*.

Maclean, J. L., Dawe, D. C., Hardy, B., & Hettel, G. P. (2002). Rice almanac. 3rd edn. CABI Publishing, Wallingford, UK pp. 2533.

Mann, R. A., Ahmad, S., Hassan, G., & Baloch, M. S. (2007). Weed management in direct seeded rice crop. *Pak. J. Weed Sci. Res*, *13*(3-4), 219-226.

McDonald, A. J., Riha, S. J., Duxbury, J. M., Steenhuis, T. S., & Lauren, J. G. (2006). Soil physical responses to novel rice cultural practices in the rice–wheat system: comparative evidence from a swelling soil in Nepal. *Soil Tillage Res. 86*(2), 163-175.

Mubeen, K., Nadeem, M. A., Tanveer, A., & Jhala, A. J. (2014). Effects of seeding time and weed control methods in direct seeded rice (*Oryza sativa* L.). *J. Animal Plant Sci. 24*(2), 534-542.

Naklang, K., Shu, F., & Nathabut, K. (1996). Growth of rice cultivars by direct seeding and transplanting under upland and lowland conditions. *Field Crops Res. 48*(2), 115-123.

Naresh, R. K., Misra, A. K., & Singh, S. P. (2013). Assessment of direct seeded and transplanting methods of rice cultivars in the western part of Uttar Pradesh. *Int. J. Pharma. Sci. Business Manage*. 1: 1-8.

Naresh, R.K., A.K. Misra and S.P. Singh. 2013. Assessment of direct seeded and transplanting methods of rice cultivars in the western part of Uttar Pradesh. Int. J. Pharmaceutical Sci. Business Manage. 1: 1-8.

Pathak, H., Tewari, A. N., Sankhyan, S., Dubey, D. S., Mina, U., Singh, V. K., Jain, N & Bhatia, A. (2011). Direct-seeded rice: potential, performance and problems–A review. *Curr. Adv. Agri. Sci. 3*(2), 77-88.

Predeepa, J. R. (2012). Aerobic rice-the next generation innovation in rice cultivation technology. *Int J. Farm Sci. 2*(2), 54-58.

Rao, A. N., Johnson, D. E., Sivaprasad, B., Ladha, J. K., & Mortimer, A. M. (2007). Weed management in direct-seeded rice. *Adv. Agron. 93*, 153-255.

Robinson, A. B., Baliunas, S. L., Soon, W., & Robinson, Z. W. (1998). Environmental effects of increased atmospheric carbon dioxide. *J. Am. Physicians Surg. 3*(5), 171-178.

Saeed, M. S., Saeed, A., & Adnan, M., (2020). Production and Utilization of Single Cell Proteins-An Overview, *Curr. Rese. Agri. Far. 1*(4), 9-12. DOI:

http://dx.doi.org/10.18782/2582-7146.117.

Sharma, P. K., Ladha, J. K., & Bhushan, L. (2003). Soil physical effects of puddling in rice-wheat cropping systems. In Improving the productivity and sustainability of rice-wheat systems: issues and impacts. Proceedings of an international symposium, held at the 2001 Annual Meetings of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Charlotte, NC, USA, 22 October 2001 (pp. 97–113). American Society of Agronomy.

Singh, S., Sharma, S. N., & Prasad, R. (2001). The effect of seeding and tillage methods on productivity of rice–wheat cropping system. *Soil Tillage Res. 61*(3-4), 125-131.

Singh, Y., Singh, V. P., Chauhan, B., Orr, A., Mortimer, A. M., Johnson, D. E., & Hardy, B. (2008). Direct Seeding of Rice and Weed Management in the Irrigated Rice-Wheat Cropping System of the Indo-Gangetic Plains. International Rice Research Institute (IRRI).

Sudhir-Yadav, Gill, G., Humphreys, E., Kukal, S. S., & Walia, U. S. (2011). Effect of water management on dry seeded and puddled transplanted rice. Part 1: Crop performance. Field Crops Res. 120(1), 112–122.

Tao, Y., Chen, Q., Peng, S., Wang, W., & Nie, L. (2016). Lower global warming potential and higher yield of wet direct-seeded rice in Central China. *Agron. Sustain. Dev.* 36(2), 24.

Velasco, L., & Pandey, S. (1998). Economics of direct-seeded rice in Iloilo [Philippines]: lessons from nearly two decades of adoption. *Philippine J. Crop Sci. (Philippines)*.

Verma, D. K., & Srivastav, P. P. (2017). Proximate composition, mineral content and fatty acids analyses of aromatic and non-aromatic Indian rice. *Rice Sci. 24*(1), 21-31.

Wassmann, R., Neue, H. U., Ladha, J. K., & Aulakh, M. S. (2004). Mitigating greenhouse gas emissions from rice-wheat cropping systems in Asia. In *Tropical Agriculture in Transition—Opportunities for Mitigating Greenhouse Gas Emissions?* (pp. 65-90). Springer, Dordrecht.

Zulfiqar, U., Hussain, S., Maqsood, M., Ishfaq, M., & Ali, N. (2020). Zinc nutrition to enhance rice productivity, zinc use efficiency, and grain biofortification under different production systems. *Crop Sci*, 61(1), 739–749.