Chapter

Recent Advances in Crop Establishment Methods in Rice-Wheat Cropping System: A Review

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Abstract

Traditional practices of growing rice and wheat in Asian countries involve a huge cost in establishment methods adopted by farmers which not only limit the yield and return but also degrade soil and require more water. Adaptation of improved crop establishment methods suitable under adverse climatic conditions is of utmost importance for scientific utilization of natural resources and to maintain the sustainability of rice- wheat cropping system. Therefore, an attempt has been made in this chapter to review precision rice establishment methodology viz., direct seeding, non-puddle/unpuddled transplanting, bed transplanting, strip tilled and single pass shallow tilled rice, double transplanting and system of rice intensification (SRI) and wheat establishment methods viz., zero tilled, strip tilled and bed planted wheat. These are recent improved crop establishment techniques that can be used under specific agro-ecological conditions for enhancing yield and resource conservation in Indo-gangetic plains of Eastern India.

Keywords: Direct seeded rice, resource use efficiency, single pass shallow tilled rice, SRI, strip tilled rice, unpuddled transplanted rice

1. Introduction

Rice–wheat cropping (RWC) system is of immense importance for the food security and livelihood of people residing in South Asian countries [1]. It occupies an area of about 18Mha in Asia, out of which 13.5 Mha lies in the Indo-Gangetic Plains (IGP) and feeds about a billion people (20% of the world population). Rice (Oryza sativa L.) is a staple food of more than 50% of the world’s population [2] and supplies 20% of total calories required by world and 31% required by the Indian population [3]. Presently, rice is cultivated in 43.79 Mha area with 112.91 Mt. production while wheat is cultivated in 29.58 Mha area with a production of 99.70 Mt. [4]. Introduction of high-yielding varieties along with improved crop management practices, access to irrigation water and chemical inputs during the green revolution period has led to impressive increase in system productivity. But recent evidences indicate a plateau in productivity and decline in total factor productivity because of continuous...
environmental degradation and socio-economic changes seen in the IGP [5, 6] highly risking the sustainability of the system [1]. Crop establishment methods are important aspects of rice wheat production technology. It refers to the sequence of events starting from sowing of seed of the crop, germination of seed, emergence of the seedling and development of seedling to a stage from where it could be expected to grow to maturity [7]. Precision crop establishment is very vital for realizing optimum plant population and agro-ecological sustainability, lack of which substantially reduces crop yield. Traditional practices not only consume more time and money but also deplete natural resources and may result in unsatisfactory crop stand. Various improved establishment methods for rice and wheat crop are reviewed and discussed in this paper.

Major challenges in puddle transplanted rice establishment

Increasing futuristic demand of water with increasing population and industries along with decreasing rainfall activity and labor scarcity are the major factors that challenge the sustainability of highwater demanding rice-wheat cropping system especially in South-Asian countries. Although puddling creates proper anaerobic condition for rice growth and reduces weed emergence but puddling and transplanting are highly labour, water, time and energy intensive leading to higher cost of cultivation. Puddling (wet tillage) consumes upto 30% of total irrigation water application in rice in case of light textured soils [8]. Also, it has been reported that on an average wheat yield is reduced by 8% when sown after puddled transplanted rice compared to wheat sown after direct-seeded rice in unpuddled conditions [9] as puddling results in destruction of soil structure and creation of hard pans at shallow depth which affect the performance of succeeding wheat crop [10]. Puddling operation in rice delays wheat planting which results in wheat yield loss of 35–60 kg day$^{-1}$ ha$^{-1}$ in the IGP [11]. Disturbing the flora and fauna of ecosystem regularly in cropping site fails to attain the climax community which provide ample opportunity of invading alien pests. Thus, the adoption of some new crop establishment techniques with higher resources conservation/use efficiency and ecological stability is of vital importance for the sustainability of the agro ecosystem.

2. Advances in crop establishment methods of rice

The alternative tillage and crop establishment methods are site-specific and therefore evaluations under wider agro-ecological conditions are needed to have significant adoption. The crop establishment methods which had got renewed interest in case of rice have been discussed below.

2.1 Direct seeded rice (DSR)

Direct seeded rice (DSR) involves the establishment of a rice crop from seeds directly sown in the field by any suitable sowing method rather than by transplanting the seedlings from nursery [12]. Three techniques of DSR viz. dry seeding, wet seeding and water seeding are known. Dry seeding involves the sowing of seeds into prepared seed bed under unpuddled and unsaturated soil conditions by broadcasting, drilling or dibbling, which is suitable for rainfed areas with severe water shortages. Dry direct-seeding with 22% increase in grain yield [13] and 35–57% of water saving [14, 15] as compared to flooded system and over 80% NUE [16], is generally adopted for upland rice [17]. The wet seeding method of DSR is suitable for irrigated
areas [18] with relatively fair amount of rainfall in which pre-germinated seeds are sown into well puddled field either by broadcasting or by using drum seeder. Drum seeding refers to the process of direct sowing of pre-germinated (sprouted) paddy seeds in puddled and leveled field after draining out the excess water by using an equipment known as drum seeder, which generally consists of 4 hyperboloid shaped drums capable of sowing 8 lines in one pass with 20 cm row to row spacing [19]. However, handling of the equipment is a problem which may lead to uneven seed distribution due to clogging of holes of the drum. In case of water seeding suitable for high rainfall areas, seeds are sown in standing water in fields where ridges and furrows are prepared prior to submergence. The depressions are created to prevent the seeds from getting drifted away and maintain favorable crop geometry.

DSR facilitates saving of resources as well as their efficient utilization and timely sowing of the subsequent crops. Although, the yield obtained in transplanted method of rice is more than that of DSR, but the net return as well as the B-C ratio is higher in case of DSR as reported by Kumar and Batra (Table 1) [20]. In the absence of water deficit stress, the faster development of DSR than transplanted rice is consistent over many findings as reported by Alam et al. [21]. And drum seeding which is a type of direct seeding is also beneficial in the same way as reported by [22] who found that the B:C ratio was higher in dry seeded rice with drum seeder (1.70) as compared to transplanting after puddling (1.54). However, the main constraint of direct seeding is the preponderance of weeds and proper crop emergence followed by establishment. The risk of yield loss in DSR is much greater (50–91%) as compared to that of conventional transplanted rice [23].

2.2 Non puddled/unpuddled transplanted rice

In case of unpuddled transplanting, the field is made ready for transplanting by a single pass strip tillage (or without tillage) followed by inundation of the field for nearly 2 days to make the land sufficiently soft for transplanting [24]. Thus, in this process the travail of puddling is omitted while the advantages of transplanting are obtained. It saves 31–76% of fuel, 25–26% of water [25] and time required for field preparation. Problems of proper establishment of the seedlings at the initial stage of germination and infestation of diseases, pest and weeds are few threats to the rice crop established by this method. Thus, growing rice by this method requires proper care and vigilance. Hossain et al. [26] reported greater yield (5.47 t ha\(^{-1}\)) and lesser fuel consumption (4.38 l ha\(^{-1}\)) in unpuddled transplanted rice as compared to the puddled transplanted rice. However, similar rice yield under puddled transplanted rice and unpuddled transplanted rice under zero tilled condition was reported in the Eastern gangetic plains [27]. Also, there was a trend of increasing grain yield in zero tilled unpuddled transplanted rice over that of puddled transplanted rice in the

| Particulars               | TPR     | DSR     |
|--------------------------|---------|---------|
| Production (q ha\(^{-1}\)) | 41.90   | 38.30   |
| Gross Return             | 107244.25 | 98142.25 |
| Net Return               | 87.28   | 1803.27 |
| Cost of Production (Rs per quintal) | 251795 | 2472.94 |
| B-C Ratio                | 1.00    | 1.02    |

Source: Kumar and Batra [20].

Table 1.
A study showing economics of TPR and DSR in Haryana (Rs ha\(^{-1}\)).
second season [28]. The practice of transplanting on unpuddled soil, suitable for low land areas, is a potential technology for those farmers who are skeptical about direct-seeded rice to avoid adverse effect of puddling on succeeding wheat crop.

2.3 Bed transplanted rice

Rice is also transplanted in bed with 15 cm height, 35 cm top width, 60 m bottom width and 25 cm furrow length [29] with rice seedlings are transplanted at the edges of beds. This method increases yield by 16% as compared to the conventional method [29]. The yield attributing characters viz. plant height, productive tillers/m², number of grains/panicle and test weight in case of rice grown on beds have been found to be at par with that of rice grown under conventional puddling as reported by Aslam et al. [30], however the B:C ratio was higher in case of bed transplanting as compared to conventional transplanting. Two types of nursery bed are possible in this method viz. dry bed and wet bed. Bed transplanting has many advantages out of which border effect on majority of the seedlings is most important. Also, irrigation can be applied efficiently in the furrows with comparatively less amount of water. The same beds can be used consequently for 5–6 years which is profitable in monetary terms. Irrigation water productivity (IWP) was significantly higher in beds to the tune of about 13% than flat transplanting during both the years of study by Sandhu et al. [31]. However, labour required for bed construction is more in this case. It is generally suitable for medium upland under irrigated condition.

2.4 Strip tilled rice

In unpuddled strip tilled rice, 4–6 cm wide and up to 6 cm deep tilled zones are made just after a little rain shower and seedlings are transplanted at a spacing of 25 cm × 20 cm which may vary according to soil conditions [24]. In this method, only 16–25% of the surface soil is disturbed and the rest remain conserved as it is which reduces the mechanical impedance on the soil surface and allows efficient use of resources as fertilizers are applied as band placement. Hossain et al. [32] reported that the yield and B-C ratio of rice was increased by 9% and 25%, respectively in the kharif season and 13% and 23%, respectively in the rabi season for strip tillage as compared to conventionally tilled rice. Adhikari et al. [33] reported that the rice grain yield under strip tillage without mulch was significantly higher than rice grown under full tillage with mulch.

2.5 Single pass shallow tilled rice

Single pass shallow tillage refers to tilling the entire soil surface upto 4–6 cm depth by using Versatile Multi-crop Planter (VMP) [34] and incorporating the residues into the field in one single go of the equipment. After tillage, irrigation is done to inundate the field for 24 hours before transplanting. Significant differences were not reported for grain yield under single pass shallow tilled (SPST) and conventional tilled rice but the gross margin was significantly higher for SPST as compared to conventional transplanting (Table 2) [24]. This method of sowing rice may be followed in both upland and medium land conditions where soil is compacted and impermeable.

2.6 Double transplanted rice

Double transplanting is a crop establishment system in which rice seedlings are transplanted twice, first on secondary nursery and then in the main field [35]. In this method, seeds are first sown in the primary nursery and subsequently after
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3 to 4 weeks, rice seedlings from secondary nursery are again uprooted and transplanted in the main field [36]. In situations where the main field is not ready for transplanting at appropriate time due to late onset of monsoon or continuous stagnation of flood water, double transplanting is advantageous producing healthy and taller seedlings that can easily overcome the adverse situation like high water depth at the time of transplanting [37, 38]. Satapathy et al., [35] reported that double transplanting resulted in higher net returns and benefit–cost ratio than normal transplanting which is owing to higher grain yield. Kumar et al. [39] also reported higher B-C ratio of 1.99 in double transplanting as compared to single transplanting with a B-C ratio of 1.27. However, this method is quite labor intensive due to the involvement of a second stage nursery and transplanting without proper skill from smaller to larger polybags could give rise to severe transplanting shock. This system is suitable for long duration rice varieties in shallow low land areas.

2.7 System of rice intensification

System of Rice Intensification (SRI) is one of most revolutionary method of rice establishment which is being adopted in many countries. It consistently outperforms conventional practices providing new possibilities for food security and poverty reduction [40]. The four main principles of SRI are early, quick and healthy plant establishment, reduced plant density, improved soil conditions through enrichment with organic matter, reduced and controlled water application. Unlike conventional method, in SRI, seedlings are transplanted at 2 leaf and 3rd phyllocron stage [41] at 8–12 days age under square planting. Latif and Abdullah [42] reported that the use of irrigation water was reduced by 52.7% in comparison to transplanted rice. In 2002, at the first international conference on SRI, 15 countries reported that the average yield of rice was twice the current average with the use of this system of rice cultivation [43]. Kumar et al. [44] reported higher grain yield and total water productivity of rice grown in SRI method as compared to normal transplanting method. Hossain et al. [45] also reported a handsome grain yield of 7.62 t/ha in SRI as compared to 6.59 t/ha in traditional method. SRI is generally suitable for areas where the soil is fertile, fine textured, well drained and maintenance of alternate wetting and drying conditions is possible. However, high labour requirement and problems faced at the time of transplanting of young seedlings are some of the constraints of this method.

3. Recent advances in crop establishment methods of wheat

The main constraint faced by wheat crop in the rice-wheat cropping system is delayed planting leading to terminal heat stress due to growing of long duration rice varieties and the time required for land preparation after harvesting of
the submerged rice crop. The crop establishment practices mentioned below are devised to manage those problems.

3.1 Zero tilled wheat

Zero tillage is an already proven resource conserving technology for wheat crop and it was found that it results in increase in crop yield by 5–7% (140–200 kg ha\(^{-1}\)) and food production by 0.7% (343000 tonnes ha\(^{-1}\)) in the Indo Gangetic plains [46]. Seed and fertilizers are placed by opening the furrows with the help of equipments like zero till ferti seed drill or Happy seeder in a single go in standing crop residues by completely avoiding the primary tillage operations. Singh et al. [47] reported that the grain and straw yield obtained by sowing of wheat by happy seeder is higher than the farmers practice in one of the two experimental locations (Table 3). This method reduces the tillage operations with a single pass and saves fuel, labour, farm machinery cost, water, fertilizers etc. [48], permits earlier wheat planting in rice-wheat system and control the problem of Phalaris minor [46]. Pandey et al. [49] reported higher grain yield (3440 kg/ha) and B:C ratio (2.38) for zero tilled wheat as compared to conventionally grown wheat with a grain yield of 3224 kg/ha and B:C ratio of 1.81 in Kailali district of Nepal. Since residue retention is a common practice in zero tillage system, so the organic matter content of the soil is also increased and soil compaction is reduced due to enhancement of biological activities in soil. The constrains of adapting zero tillage in wheat under RW system of developing countries are the small size of land holdings of small and marginal farmers and the involvement of lumpy technology (i.e. non-divisible piece of machinery) [5, 6] involving high procurement cost.

3.2 Bed planted wheat

In this method of wheat crop establishment, which is synonymous to furrow irrigated raised bed (FIRB), the land is cultivated traditionally and ridges/raised beds and furrows are prepared by using a raised bed planting machine where seeds are planted in rows and irrigation water is applied in furrows. In rice-wheat cropping system, raised beds are newly prepared for wheat and then in the next season rice is grown on the same bed under zero tillage with required repairing of the beds [50]. The most beneficial aspect of this method as mentioned in case of rice is the border effect imparted to maximum number of plants. Bed planted wheat also showed better performance with significantly highest number of tillers per running meter compared to others establishment methods viz. broadcasting and criss cross sowing, in the middle Gangetic plain regions during both the experimental years [51]. Mollah et al. [50] reported a yield increase of 21% and water saving of 41–46% with a 70 cm wide bed with two rows over conventional method in wheat. However,

| Treatment          | Grain yield (q ha\(^{-1}\)) | Straw yield (q ha\(^{-1}\)) |
|--------------------|-----------------------------|-----------------------------|
|                    | Jalandhar       | Patiala        | Jalandhar      | Patiala        |
| Rotovator          | 41.19           | 44.52          | 63.02           | 68.1            |
| Happy Seeder       | 43.63           | 49.53          | 66.75           | 75.8            |
| Farmers practice   | 42.47           | 46.02          | 64.98           | 70.4            |

Source: Singh et al., 2013.

Table 3.
A study showing influence of sowing methods on grain and straw yield of wheat.
the requirement of labour for bed preparation and favorable soil texture are some constraints in the adoption of this method.

3.3 Strip tilled wheat

In strip till planting, seed and fertilizers are placed simultaneously in a single operation by tilling the planting strips with a width of 4–6 cm [52] and depth of 2–7 cm. Unlike zero tillage, the row zone is completely pulverized with standing crop residues in the field. This method facilitates early establishment of wheat crop, reduces soil erosion from surface and efficient utilization of resources such as labour, fuel, soil etc. The fuel consumption in strip tillage was reduced by 57% and 38%, respectively as compared to conventional tillage and minimum tillage [52]. Usage of strip tillage produces high crop yields with lower production costs and provides better soil erosion control compared to conventional tillage [53]. Hossain et al. [32] reported higher yield of wheat in this method as compared to conventional method in all the three experimenting years. This method is recommended for medium land with irrigation facilities. However, higher cost of the strip till machine poses a constraint for the adoption of this method.

4. Conclusion

Newly developed techniques are precision establishment techniques, use of need based crop establishment technology conserves the scarce resources and reduces the crop establishment cost of rice-wheat system. These techniques are machine based which help in mechanization and optimization of resources. Thus, these techniques should be promoted to obtain higher net return, sustainable intensification, maintenance of soil health and reduction in environmental pollution.

5. Future thrust

Weed management is a major challenge in these crop establishment methods as new complexes of weed flora are being observed by the farmers. Therefore, efficient weed management practices should be researched for wider adaptability of these techniques.
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References

[1] Ladha, J. K., J. E. Hill, J. M. Duxbury, R. K. Gupta, and Buress, R. J. (2003). Improving the productivity and sustainability of rice-wheat systems: Issues and impacts. Madison, Wisconsin, U.S.A., American Society of Agronomy, crop science Society of America, Soil Science Society of America.

[2] Fageria, N.K. (2007). Yield physiology of rice. Journal of Plant Nutrition**30**: 843-879.

[3] Anonymous. (2011). Rice Calorie Supply as Percentage of Total Calorie Supply, by Country and Geographical Region, 1961-2005. Available from: (accessed 24.2.11).

[4] Anonymous. (2018). Agricultural Statistics at a Glance, Government of India, Ministry of Agriculture & Farmers Welfare, Department of Agriculture, Cooperation & Farmers Welfare Directorate of Economics & Statistics.

[5] Erenstein, O., J. Hellin, and P. Chandna. (2007a). Livelihoods, Poverty, and Targeting in the Indo-Gangetic Plains: A Spatial Mapping Approach. Research report. New Delhi, International Maize and Wheat Improvement Center and Rice-Wheat Consortium.

[6] Erenstein, O., R. K. Malik, and S. Singh. (2007b). Adoption and impacts of zero tillage in the irrigated rice-wheat systems of Haryana, India. Research Report. New Delhi, International Maize and Wheat Improvement Center and Rice-Wheat Consortium.

[7] Jat, M.L., Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Jat, A.S., Kumar, V., Sharma, S.K., Kumar, V. and Gupta, R. (2009). Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil physical properties. Soil & Tillage Research**105**: 112-121.

[8] Aslam, M., Qureshi, A.S. and Horinkova, V.M. (2002). Water saving strategies for irrigated rice. Journal of Drainage and Water Management**6**(1).

[9] Kumar, V., Bellinder, R.R., Gupta, R.K., Malik, R.K. and Brainard, D.C. (2008). Role of herbicide-resistant rice in promoting resource conservation technologies in rice–Wheat cropping systems of India: A review. Crop Protection**27**, 290-301.

[10] Hobbs, P. and Morris, M. (1996). Meeting South Asia’s future food requirements from rice-wheat cropping system: Priority issues facing researchers in the post-green revolution era. NRG Paper, 96(01).

[11] Pathak, H., J.K. Ladha, P.K. Aggarwal, S. Peng, S. Das, Y. Singh, B. Singh, S.K. Kamra, B. Mishra, A.S.R.A.S. Sastrī, H.P. Aggarwal, D.K. Das, and R.K. Gupta. (2003). Trends of climatic potential and on-farm yields of rice and wheat in the indo-Gangetic Plains. Field Crops Research**80**:223-234.

[12] Kaur, J. and Singh, A. (2017). Direct Seeded Rice: Prospects, Problems/Constraints and Reachable Issues in India. Current Agriculture Research Journal 5(1), 13-32.

[13] Zhu, L. (2008). A report on dry direct seeding cultivation technique of early rice. Journal of Guangxi Agricultural and Biological Science 23:10-11. (In Chinese with English abstract)

[14] Sharma, P.K., Bhushan, L., Ladha, J.K., Naresh, R.K., Gupta, R.K., Balasubramanian, B.V. and Bouman, B.A.M. (2002). Crop-Water Relations in Rice-Wheat Cropping under Different Tillage Systems and Water Management.
Practices in a Marginally Sodic, Medium-Textured Soil. Water-wise rice production. International Rice Research Institute, Los Baños, 223-235.

[15] Singh, A.K., Choudhury, B.U. and Bouman, B.A.M. (2002). Effects of Rice Establishment Methods on Crop Performance, Water Use, and Mineral Nitrogen. Water-wise rice production. International Rice Research Institute, Los Baños, 237-246.

[16] Wilson, C., Slaton, N., Norman, R. and Miller, D. (2000). Efficient use of fertiliser. Rice Production Handbook, University of Arkansas, Division of Agriculture, Cooperative Extension Service, 8, 51-74.

[17] Gupta, P.C. and O'Toole, J.C. (1986). Upland Rice-a Global Perspective. IRRI, Manila.

[18] IRRI Rice Knowledge Bank, http://wwwknowledgebank.irri.org/

[19] Singh, U.V., Kumar, D. and Moses, S.C. (2016). Performance evaluation of manually operated paddy drum seeder in puddle field. Journal of Agriculture and Veterinary Science 9(6): 69-83.

[20] Kumar, R. and Batra, S.C. (2017). A comparative analysis of DSR technology Vs. transplanted method in Haryana. Economic Affairs 62(1): 169-174.

[21] Alam, M. J., Humphreys, E., Sarkar, M. A.R. and Yadav, S. (2018). Comparison of dry seeded and puddled transplanted rainy season rice on the high Ganges River floodplain of Bangladesh. European Journal of Agronomy 96: 120-130.

[22] Kumar, V., Singh, S., Sagar, V. and Maurya, M.L. (2018). Evaluation of different crop establishment methods of rice on growth, yield and economics of rice cultivation in agro-climatic condition of eastern Uttar Pradesh. Journal of Pharmacognosy and Phytochemistry 7(3): 2295-2298.

[23] Rao, A.N., Johnson, D.E., Sivaprasad, B., Ladha, J.K. and Mortimer, A.M. (2007). Advances in Agronomy 93, 153-255.

[24] Haque, M.E., Bell, R.W., Islam, M.A. and Rahman, M.A. (2016). Minimum tillage unpuddled transplanting: An alternative crop establishment strategy for rice in conservation agriculture cropping systems. Field Crops Research 185, 31-39.

[25] Islam, A.K.M.S., Hossain, M.M., Saleque, M.A., Rahman, M.A., Karmakar, B. and Haque, M.E. (2012). Effect of minimum tillage on soil properties, crop growth and yield of aman rice in drought prone northwest Bangladesh. Bangladesh Agronomy Journal 15(1): 43-51.

[26] Hossain, M.M., Rabbani, M.A.E., Elahi, H.M.T., Sarkar, S., Saha, C.K., Alam, M.M., Kalita, P.K. and Hansen, A.C. (2017). Options for Rice Transplanting in Puddle and Un-Puddled Soil. 2017 ASABE Annual International Meeting, Spokane, Washington.

[27] Islam, S., Gathala, M.K., Tiwari, T.P., Timsina, J., Laing, A.M., Maharjan, S., Chowdhury, A.K., Bhattacharya, P.M., Dhar, T., Mitra, B., Kumar, S., Srivastwa, P.K., Dutta, S.K., Shrestha, R., Manandhar, S., Sherestha, S.R., Paneru, P., Siddquie, N.-E. A., Hossain, A., Islam, R., Ghosh, A.K., Rahman, M.A., Kumar, U. and Rao, K.K., Gerard, B. (2019). Conservation agriculture based sustainable intensification: increasing yields and water productivity for smallholders of the Eastern Gangetic Plains. Field Crops Research 238: 1-17. https://doi.org/10.1016/j.fcr.2019.04.005.

[28] Chaki, A. K., Gaydon, D.S., Dalal, R.C., Bellotti, W.D., Gathala, M.K., Hossain, A., Siddquie, N.E.A. and Menzies, N.W. (2020). Puddled and zero-till unpuddled transplanted rice
are each best suited to different environments- an example from two diverse locations in the eastern Gangetic Plains of Bangladesh. *Field Crops Research* 262: 108031.

[29] Bhuyan, M.H.M, Ferdousi, M.R. and Iqbal, M.T. (2012). Yield and growth response to transplanted aman rice under raised bed over conventional cultivation method. International scholarly research network. Article ID 646859, 8 pages.

[30] Aslam, M., Hussain, S., Ramzan, M. and Akhter, M. (2008). Effect of different stand establishment techniques on rice yields and its attributes. Journal of Animal and Plant Sciences 18 (2-3): 80-82.

[31] Sandhu, S. S., Mahal, S.S., Vashist, K.K., Buttar, G.S., Brar, A.S. and Singh, M. (2012). Crop and water productivity of bed transplanted rice as influenced by various levels of nitrogen and irrigation in Northwest India. *Agricultural Water Management* 104: 32-39.

[32] Chahal, M.I., Sarker, M.J.U. and Haque, M.A. (2015). Status of conservation agriculture based tillage technology for crop production in Bangladesh. Bangladesh Journal of Agricultural Research 40(2): 235-248.

[33] Adhikari, U., Justice, S., Tripathi, J., Bhatta, M.R. and Khan, S. (2015). Evaluation of Non-puddled and Zero till Rice Transplanting Methods in Monsoon Rice. Paper Presented at International Agricultural Engineering Conference, AIT Bangkok, Thailand.

[34] Haque, M.E., Bell, R.W., Islam, A.K.M.S., Sayre, K. and Hossain, M.M. (2011). Versatilemulti-crop planter for two-wheel tractors: An innovative option for smallholders. In: Gilkes, R.J., Prakongkep, Nattaporn (Eds.), 5th World Congress of Conservation Agriculture Incorporating 3rd Farming Systems Design Conference, Brisbane, Australia, 102-103.

[35] Satpathy, B.S., Singh, T., Pun, K.B. and Rautarat, S.K. (2015). Evaluation of rice (Oryza sativa) under double transplanting in rainfed lowland rice ecosystem of Assam. Indian Journal of Agronomy 60(2): 245-248.

[36] Das, S.R. (2006). Indian diversified rice cultivation. Souvenir, 63-70. *Second International Rice Congress*, 9-13 October, 2006, New Delhi. Doi:10.5402/2012/646859.

[37] Ashim, S.S., Thakuria, K. and Kumari, K. (2010). Double transplanting of late transplanted *Sal* rice under lowland situation. Oryza 47(4): 328-330.

[38] Rautray, S.K. (2007). Strategies for crop production in flood affected areas of Assam. Indian Farming 57(6): 23-26.

[39] Kumar, V. S., Nayak, A. K., Satapathy, B. S., Munda, S., Tripathi, R. and Khanam, R. (2019). *Indian Farming* 69(05): 36-38.

[40] Thakur, A. K., Mohanty, R. K., Singh, R. and Patil, D. U. (2015). Enhancing water and cropping productivity through integrated system of Rice intensification (ISRI) with aquaculture and horticulture under rainfed conditions. *Agricultural Water Management* 161: 65-76.

[41] Veeramani, P., Singh, R.D. and Subrahmaniyan, K. (2012). Study of phyllochron- system of Rice intensification (SRI) technique. *Agricultural Sciences Research Journal* 2(6): 329-334.

[42] Latif, K.M.A.E. and Abdullah, R. (2012). Rice Yield and Water Saving in the System of Rice Instensification (SRI): Review. Minia International Conference for Agriculture and Irrigation in the Nile Basin Countries, El-Minia, Egypt.
[43] Uphoff, N. (2002). Questions and Answers about the System of Rice Intensification (SRI) for Raising the Productivity of Land, Labour and Water. Cornell International Institute for Food, Agriculture and Development, Cornell University, Ithaca, NY.

[44] Kumar, R. M., Surekha, K., Padmavati, C., Rao, L.V.S., Latha, P.C., Prasad, M.S., Babu, V.R., Ramprasad, A.S., Rupela, O.P., Goud, V., Raman, P.M., Somashekar, N., Ravichandran, S., Singh, S.P. and Viraktamath, B.C. (2009). Research experiences on System of Rice Intensification and future direction. Journal of Rice Research 2(2): 61-71.

[45] Hossain, T., Hossain, E., Nizam, R., Bari, F., A. S. M. and Chakraborty, R. (2018). Response of Physiological Characteristics and Productivity of Hybrid Rice Varieties under System of Rice Intensification (SRI) over the Traditional Cultivation. International Journal of Plant Biology and Research 6(2): 1085.

[46] Erenstein, O., and Laxmi, V. (2008). Zero tillage impacts in India’s rice-wheat systems: A review. Soil and Tillage Research 100 (1–2): 1–14.

[47] Singh, A., Kang, J. S. and Kaur, M. (2013). Planting of wheat with happy seeder and rotovator in rice stubbles. Indo-American Journal of Agricultural and Veterinary Sciences 1(2), 32-41.

[48] Yadav, A., Malik, R. K., Chouhan, B. S., Kumar, V., Banga, P. S., Singh, S., Yadav, J. S., Punia, S. S., Rathee, S. S. and Sayre, K. D. (2002). Feasibility of Raising Wheat on Furrow Irrigated Raised Beds in South-Western Haryana. Presented in International Workshop on, Herbicide resistance management and zero tillage in rice-wheat cropping system, Hisar, Haryana, India.

[49] Pandey, B. P., Khatri, N., Pant, K. R., Yadav, M., Marasini, M, Paudel, G. P. and Bhatta, M. (2020). Zero-till wheat (Triticum aestivum L.): A Nepalese perspective. Fundamental and Applied Agriculture 5(4): 484-490.

[50] Mollah, M.I.U., Bhuiya, M.S.U. and Kabir, M.H. (2009). Bed planting- a new crop establishment method for wheat in Rice-wheat cropping system. Journal of Agriculture and Rural Development 7(1&2): 23-31.

[51] Raghuvanshi, N. and Singh, B. N. (2020). Impact of sowing method and nitrogen management on growth of wheat (Triticum aestivum L.). International Journal of Chemical Studies 8(3): 2771-2775.

[52] Hossain, M.I., Gathala, M.K., Tiwari, T.P. and Hossain, M.S. (2014). Strip tillage seeding technique: A better option for utilizing residual soil moisture in rainfed moisture stress environments of north-West Bangladesh. International Journal of Research Development in Engineering and Technology 2(4).

[53] Laufer, D., Koch, H.J. (2017). Growth and yield formation of sugar beet (Beta vulgaris L.) under strip tillage compared to full width tillage on silt loam soil in Central Europe. European Journal of Agronomy 82: 182-189. https://doi.org/10.1016/j.eja.2016.10.017.