International Journal of Plant & Soil Science

33(6): 9-21, 2021; Article no.IJPSS.67868
ISSN: 2320-7035

Sustainable Issues and Crop Diversification of the Rice-Wheat Cropping System for Higher Productivity and Resource Use Efficiency: A Review

Kuldeep Singh[1*], Sachin Dhanda[1], Kartik Sharma[2] and Dheeraj Panghaal[3]

[1]Department of Agronomy, CCS Haryana Agricultural University, Hisar-125004 (Haryana), India.
[2]Department of Agronomy, Punjab Agricultural University, Ludhiana- 141004 (Punjab), India.
[3]Department of Soil Science, CCS Haryana Agricultural University, Hisar-125004 (Haryana), India.

Authors' contributions

This work was carried out in collaboration among all authors. Author KS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SD and KS managed the analyses of the study. Author DP managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2021/v33i630439
Editor(s):
(1) Dr. Hon H. Ho, State University of New York, USA.
Reviewers:
(1) Akshit Chaudhary Charan Singh, Haryana Agricultural University, India.
(2) Barlin Orlando Olivares Campos, University of Cordoba, Spain.
Complete Peer review History: http://www.sdiarticle4.com/review-history/67868

Review Article

Received 09 February 2021
Accepted 19 April 2021
Published 24 April 2021

ABSTRACT

The rice-wheat cropping system (RWCS) played a significant role in national food security. This system is having a huge potential to feed the increasing population of India. But with continuous adoption of the rice-wheat system, different issues and challenges have emerged and resulted in the decline or stagnated the productivity of this system. In these conditions' diversification of the RWCS can be a viable option for higher productivity, profitability and efficient and sustainable use of available natural resources. This review mainly highlighted the major issues associated with the rice-wheat cropping system in India along with the alternate cropping system for crop diversification by substitution various crops *viz.* legume, maize, oilseed, fodder, vegetables and cash crop to tackle them. The comparison of various cropping system in term their crop productivity, economics analysis, water and nutrient productivity, and maintaining soil health.

**Corresponding author: E-mail: kuldeepvartia73@gmail.com;*

Keywords: Rice-wheat; soil health; pollution; residue management; crop rotation; diversification.

1. INTRODUCTION

The rice-wheat cropping system (RWCS) is most prominent and world's largest agricultural production system, covering an estimated area of13.5 million ha (Mha) of cultivable land in South Asia [1], mostly in India, Bangladesh, Pakistan and Nepal, but also large areas in China [2,3]. It has played a significant role in the food security of the country. However, in recent years sustainability of the RWCS is adversely affected as yields of both rice and wheat are either stagnant or decreasing due to deterioration of soil health, environmental pollution, decrement in factor productivity or input-use efficiency; increase in cultivation costs and reduction in profit margins [4, 5]. The over exploitation of underground water which leads to decline in water table [6,7] and the unattended intervening periods also affecting the sustainability of the RWCS (Bhatt and Kukal 2014a,b); [8-10]. In rice during conventional tillage (wet tillage in standing water)irrigation is applied in rice 5–6 times to facilitate land preparation and puddling before rice seedling transplanting. The intensive tillage and puddling for rice have, however, caused several problems, including the development of hard plough-pan, decreased input-use efficiency, declined yields, hiked insect pest outbreak and global warming [1, 11, 12]. Seed bed preparation operations during wheat crop oxidizes the once hidden organic matter, break the macro-aggregates into the micro-aggregates which adversely affect the soil properties [13,14]. The system of rice followed by wheat require more water, capital, energy labor intensive [3,15,16].

The continuous cropping of the RWCS during last four decades has been causing many second generation problems, viz. emergence of multi-nutrient deficiencies [17], formation of hard pan, declining factor productivity and buildup of problematic weeds like *Phalaris minor* in wheat and (frequent and widespread insect pest infestations [18]. Moreover, notwithstanding these issues, the open field burning of crop residues particularly the rice residues results in emissions of greenhouse gases (GHGs), resulting in decline in carbon (C) sequestration in the RWCS of the region [19]. Evidence suggests that the RWCS is facing several unsustainability issues in the NW IGPs, especially in the context of conserving natural resources and environmental sustainability [3,1]. Continues following cereal-cereal sequences are more exhaustive and put a heavy demand on soil resources as compared to cereal-legume and cereal-oilseed sequences [20]. In these conditions' diversification of the RWCS can be a viable option.

Crop diversification refers to a strategy of shifting from less profitable and unsustainable crop or cropping system to more profitable and sustainable crop/cropping system through the use of resources in the best possible way by changing and modifying the spatial and temporal crop/cropping activities on a particular farm. Inclusion of pulses, oilseed sand vegetables in the system is more beneficial than cereals after cereals, and such inclusion in a sequence changes the economics of the crop sequences (Gangwar et al.,2004) [21]. Like, in areas of Punjab and Haryana where ground water table is declining very fast, water guzzling crop of rice can be replaced with soybean and early pigeon pea [22]. This publication seeks to highlight almost all the sustainability issues originated due to intensive cultivation of the RWCS and alternate crop sequences to save the region without deteriorating the God gifted resources viz. soil and water.

2. SUSTAINABLE ISSUES OF RICE WHEAT CROPPING SYSTEM

The RWCS is a main feature of the Indo-Gangetic Plains. However, continues following the rice followed by wheat cropping system for long period has threaten the substantiality of system and caused degradation of natural resources (groundwater, soil) to a great extent.

3. SOIL RELATED ISSUES

3.1 Degrading Soil Structure

The RWCS are characterized by a diverse edaphic environment. Wet tillage (puddling; tillage in standing water—a pre-requisite under conventional tillage (CT) with an aim of reducing percolation losses, ease transplanting and suppress weeds. However, its negative effects through structural degradation on upland crops are of concern [23,24]. Wet tillage induces the formation of hardpan with higher soil bulk density that affects root proliferation in terms of root geometry and architecture of succeeding wheat crop [15,16]. During wheat conventionally seedbed prepared by disking, tilling and finally planking which resulted in the exposure of the once hidden organic matter to the air which ultimately leads to the oxidation of organic matter. These practices in the RWCS ultimately lead to the overall structural degradation of the soil structure like conventional systems in tropical climates as reported by the studies of Olivares [25] and Olivares et al. [26].

3.2 Declining Soil Health

The RWCS is a major reason of declining inorganic carbon in soil which plays a key role in improving soil health and determines soil fertility. As carbon is the central element that mediating the release of various plant nutrients in soil, thus determines yield of crops. Simultaneously, it improves the soil resilience through buffering various soil properties, which provide good soil environment for plant growth. However, conventional rice in the RWCS requires puddling for seed bed preparation, which needs more water and labor; and in turn breaks soil aggregates exposing the soil for oxidation of organic carbon [27]. Thus, the conventional cultivation of rice-wheat leads to depletion of SOC at the rate 0.13 t $ha^{-1}yr^{-1}$ from 0 to 0.6 m depth of eastern IGP [28]. During burning of rice residues straw almost all C, 90% of N, 60% of S and 20–25% of P and K in are which ultimately decline soil health [29]. According to Singh [30], in Haryana 3 percent soils during 1980 had low P content and by 1995, the earlier figure jumps to 73 percent, while low N content area increased to a non-significant extent (from 89 to 91 percent). Soils with higher K values had come down from 91 percent (in 1980) to 61 percent (in 1995). The intensive RWCS disturbed the nutrient balance in upper vadose zone [31]. Crop Diversification seems to be one of the pragmatic solutions of the aforesaid problem. Inclusion of legume in cereal–cereal rotation enhances soil quality and raises organic carbon level in soil, also it reduces the soil loss [32] and water erosion in agricultural areas [33].

3.3 Multiple Nutrient Deficiencies

Earlier only macro nutrients have to supplied through application of fertilizers but now due to declining sol health, the micronutrients also have to supplied because of their deficiency in the RWCS [34]. There are many reports of increase in the yield with the application of sulphur in the RWCS [35,36]. Further there are reports of manganese deficiency in Punjab and boron deficiency in West Bengal [37]. The application of borax is very effective in improving the wheat yield by fulfilling the deficiency. The selenium toxicity is also an upcoming issue in the RWCS as it was reported in certain regions of Punjab especially in Hoshiarpur and Nawanshahr districts. Thus, there is need to shift from this cereal-cereal based cropping system towards legume based cropping system. Further, the incorporation of rice residue resulted in improving the soil fertility and enhanced the concentration of N, P and K in the soil [38].

4. WATER RELATED ISSUES

4.1 Declining Underground Water Table

The RWCS has aggravated the problems associated with declining groundwater table resulting in decreased crop productivity. The conventional crop establishment techniques for the RWCS are highly exhaustive in terms of labor, water and power, but especially water owing to the significantly higher water demand of rice [3], Bhatt and Kukal 2018; [15,16]. The Punjab and Haryana in NW Indian IGPs are producing at the cost of their natural resources [39]. Among rice and wheat cropping systems, irrigated rice, is a heavy water consumer as it took around 5000 liters of water to produce 0.01 quintal of rice. The groundwater is being continuously pumped out from the below ground aquifer since 1970s that has resulted in drawdown of groundwater in NW IGPs [7]. It would also reduce the share proportion of agriculture sector by 8-10% up to 2025 [40] because of rising water demand by other allied sectors Mahajan et al. [41] predicted that the annual per capita water availability in Indiais expected to decrease from 1600 $m^3$to 1000 m^3 by 2025. The RWCS consumes about 11,650 m^3 ha^{-1} water out of which 7650 m^3 ha^{-1} is by rice. Free electricity for the agricultural sector further complicated this condition. Centrifugal pumpsare generally a failure now and submersible pumps are the only option left because of deeper underground water. In the NW IGPs, the ground water levels are declining at 0.1–1.0 m $year^{-1}$ due to poor infrastructure and blind reliance on the groundwater [3,7]. Thus, the water table in some pockets is declining down at alarming rates. There is a need to address the issues relating sustainable crop production and rational water use.

4.2 Groundwater Pollution

The declining groundwater tables and excessive use of the fertilizers/insecticides in the RWCS pollutes the underground water quality [15].

Excessive use of N-fertilizers resulting to leaching of nitrates leads to the pollution of ground water appears to be a serious concern. High nitrate content in ground water in intensively cultivated RWCS was reported by Bajwa [42]. The situation is worse in coarse-textured soils where use of N fertilizer is still higher with excessive irrigations as generally recommendation to be 25% higher than loam soil. This is true also for the South-Western districts of the Punjab, due excessive use of fertilizers and insecticides the underground water is unfit for drinking or even for the irrigation. Further, this causes a health disorders as more cancer cases were reported from this pocket in such an extent that a “CANCER TRAIN” was running to Rajasthan for treating the cancer patients. Thus, increasing ground water pollution is the major issue, which must be attended to as soon as possible by creating social awareness or by forming legal binding and must be pay attention to it under ground water pollution is an emerging issue So, the fertilizers should be depending uponthe soil test reports is the key to profitability of the RWCS in the region (Bhatt, 2013)

4.3 Crop Residue Problem

In NW IGPs, Haryana, Punjab and Uttar Pradesh in India are the major residues producing in Punjab. Sidhu and Beri [43] reported a total rice straw production of ~19 million tons (Mt), of which ~78% was burnt in open fields. Of all systems, the RWCS is the largest producer of crop residues. A total of 350 × 106 kg $year^{-1}$ residue is generated in India, of which rice residue shares a significant portion (~ 51%) followed by wheat residues (~ 21%) (Singh and Sidhu 2014). The management of wheat residues on the other hand has not been a major issue. Wheat residues in NW IGPs are being used as fodder, while rice residues are not preferred by animals because rice straw contains higher silica content than wheat straw (~ 9–14% vs. ~4–8%) (Singh and Sidhu 2014). Farmers with no alternative options and due to the shorter window period between rice harvest and wheat sowing prefer to burn most rice residues at the site/field itself to dispose of straw (Singh et al. 2020a). Therefore, crop residue burning in the RWCS has now been a severe problem causing soil degradation and GHGs emissions (Singh et al. 2020a).

4.4 Environments Pollution

In the RWCS management crop residues is a major challenge. Due to the shortage of time period between harvesting of rice crop and timely sowing of succeeding wheat crop farmer goes for burning the crop residues in open field in NW IGPs. Beri et al. [44] reported that about 80–84% of the rice crop residues and14–20% of wheat residues are burnt in the Indian Punjab. Thus, the burning of large quantities of rice and wheat residues produced under the RWCS have raised serious environmental complications as most of them are burnt in open fields producing GHGs, viz. CO_2, CO, CH_4, N_2O, NO_2 and SO_2 [18] and causing air pollution (Gupta et al., 2004), smoldering of tremendous amount of nutrients and degrading soil physical and biological health (Samra, Bijay& Kumar, 2003); [45]. In Punjab, rice residue burning is considered responsible for the loss of 0.7 Mt N $year^{-1}$ apart from considerable quantities of annual GHGs emissions: CO2 (~ 70%), CO (~ 7%), CH4 (~ 0.66%) and N2O (~ 2.1%) [46].

During the early November 2017, NASA satellite images identified the burning hot spots and marked the intensity of residue burning as ‘very high,’ more particularly of rice residue burning in Haryana, Punjab, western Uttar Pradesh and Uttarakhand in NW IGPs [47]. The open field residue burning has resulted in air pollution in vast geographical areas causing several human and animal health environment-related issues. The burning of left out residues is a major contributor to reduced airquality, human respiratory ailments, and the death of beneficial soil fauna and microorganisms. Apart from loss of carbon, up to 80 percent loss of N and S, 25 percent of P and 21 percent of K occurs during burning [48]. Solution to avoid burning of rice straw would be to employ it as a mulch material in the upcoming wheat crop to improve crop yields, conserve soil moisture, and save environment.

5. GLOBAL WORMING

The RWCS produces huge crop residues which generally burnt onto the field for the timely sowing of the wheat crop. Flaming of farm residues generates ample amount of greenhouse gases and aerosols and other hydrocarbons to the atmosphere affecting the atmospheric composition. For example, 70%, 7%, 0.66 % of C and 2.09% of N evolved as CO_2, CO, $CH_4$and N_2O upon burning of rice straw [49]. This change might have direct or indirect effect on the radiation balance. These gases may lead to a regional increase in the levels of aerosols, acid deposition, increase in tropospheric ozone and depletion of the ozone layer which protects us from harmful sunrays.

6. SHIFTS IN WEED FLORA AND HERBICIDAL RESISTANCE

The intensive cultivation of rice–wheat sequence leads to the weed flora simplified with grasses. Weeds compete with the main plants for light, water and nutrients and in turn decrease over all and productivity of the system. In flooded rice ecosystems, the major weed floras are *Echinochloa colona* and *Echinochloa crusgalli*. The repeated wet tillage and water stagnation in puddled transplanted rice (PTR) help get rid of the hardy weeds and increase the efficiency of application of selective herbicides. The direct-seeded rice (DSR), which has been gaining ground in labor scarce South Asian countries, is constrained by the prevalence of many weeds including *Digitaria sanguinalis, Leptochloa chinensis, Dactyloctenium aegyptium, E. colona*and *Cyperus* spp. [50,51,52]. Changes in establishment method, technology and weed management practices in dry direct-seeded rice resulted in diverse weed composition. The weed flora in the DSR is different than in the PTR. Their weed management practices are therefore different requiring different herbicides. The zero tillage had been reported to increase weed density than conventional tillage (CT) [53,54,45] (Kumar et al., 1988) and higher weed dry biomass [54]. Modifying tillage practices will certainly affect the placement of weed seeds in the soil [53], and this may affect the relative abundance of weed pressure in the field.

Under zero tillage, a higher fraction of weeds presents near or close to the soil surface after crop planting [54], which received higher fraction of light, water and nutrients for their better proliferation. Under conventional tillage (CT), however, weeds are deeply buried as per tillage and deeply buried weeds are not have enough chances to proliferate better due to lesser water, light and nutrients. The soil disturbance caused by tillage systems places weed seeds at different depths, which differ in availability of moisture, diurnal temperature fluctuation and light exposure, and activity of predators [53]. All these attributes have the potential to influence the behavior of weed seed banks. Further, lesser herbicide efficacy observed in ZT plots as compared to the CT plots led to higher weed pressure which resulted in lower grain yields in the former plots [54]. The application of the same herbicide molecule for long time has resulted in the development of resistance against herbicides due to enzyme acetoacetate synthase [55, 56]. It has been ascribed to strong selection pressure exerted by these herbicides [57]. Further, it is observed that new weeds viz. *Sphenocleazeylanica* in rice and *Malvapatviflora*, *Rumexretroflexusin* wheat occurred with time with intensive rice–wheat cropping system which are more difficult to control and, in some cases, observed to be more resistance to the available herbicides. Integrated weed management is the best option to control the new emerging weeds in a moresustainable way. Along with the *Phalaris minor* resistance, a new case of resistance has been reported in *Rumexdentatus* to metsulfuron methyl in Haryana and Punjab states of India [58,59].

7. ALTERNATE CROPPING SYSTEM FOR CROP DIVERSIFICATION OF THE RWCS

The rice- wheat rotation is not sustainable, as currently practiced due to its serious problems and environmental threats, *viz*. over exploitation of ground water, soil degradation, intensive use of chemical fertilizers and pesticide, which enhanced groundwater pollution, crop residue burning to result in environmental pollution, enhanced greenhouse gas emissions etc. [60]. An urgent need is felt for crop diversification with remunerative, less risky, and eco-friendly crops which helps in restoring soil health and improve farmer income with efficient utilization of natural resources.

8. DIVERSIFICATION WITH MAIZE

Maize is major crop among cereals and viable option for replacing of rice. Maize is also known as king of cereals due to its high genetic yield potential and as considered as ‘future cereal’ as yield of rice and wheat showing stagnation. It is the important source of human nutrition and health and can be use fodder for animals Shah et al. [61]. Maize cultivation helps in improving the soil health and saving water. It the saving of water to the tune of 90% maize cultivation instead of paddy (Maize Summit, 2018). Maize being a C_4 plant, has an advantage over C_3 rice crop because it can very efficiently use the atmospheric CO_2. So, it has more potential for crop diversification in the rice wheat cropping system, Singh et al. [62] Dass et al. [63]. It is Maize is grown at wider spacing than to other cereal crops. Among other cereals, other crops *viz*. sorghum and pearl millet, highly efficient in using water can be replaces with rice [64,65]. However, have low productivity and are suitable for rainfed condition, these seasonal conditions of rainfall influence the zoning of tropical crops, as indicated by studies of Olivares et al. [66] Olivares et al. [67] and Cortez et al. [68].

9. DIVERSIFICATION WITH LEGUMES, OILSEED CROPS AND FODDER CROP

The legumes play very crucial role in improving soil health and sustaining the crop productivity with the efficient use of natural resources and it helps in reducing use of external input (fertilizer red) by fixing the atmospheric nitrogen in soil and restoring soil fertility Singh et al. [62]. The inclusion of pulse crop in continuous cereal cropping systems such as the RWCS has ameliorative effect on long term basis, it is emphasized by several others [69,70,71]. Ali et al., 2012; Stagnari et al., 2017 2016). In IGP, the Legumes crops constitute13.6% area and 15.8% of the total production of the country. The issue for concern is that both area and production of legumes are declining (Ali et al., 2000). Pulses found a very good position in rice-fallow system which was occurred on nearly 11.7 million ha area (Gosh et al., 2012). The crop diversification with legumes and oilseed crop in the RWCS is beneficial for soil as required minimum tillage and low water requirement than rice crop [72]. The major legume, oilseed and fodder crops that can substitute rice in the IGPs are pgeon-pea, groundnut, soybean and berseem. The some important the legume, oilseed and fodder-based cropping systems are pigeon pea-wheat, groundnut-wheat and soybean-wheat. Legumes and oilseeds crop like Black gram *(Vigna mungo*), Mung bean (*Vigna radiata*) and Sunflower (*Helianthus annuus*) are mainly grown during spring/summer season and to a small extent during rainy (*Kharif*) season. The significance of inclusion of legume in the RWCS was mentioned by Singh et al. [69] and Chaudhary et al. [73]. The substitution of forage crop such as berseem with rice in the RWCS help in reducing weed infestation especially *Phalaris minor* in succeeding wheat crop [74].

10. DIVERSIFICATION WITH CASH CROPS

Sugarcane and cotton are most important cash crops of India having high economic returns. These crops are the available options for diversification of rice in traditionally RWCS. Cotton is currently the leading fiber crop world wide and it is known as “White Gold”. It plays an important role in the in agriculture as it provides the raw material for and industrial activities of India. This can be replacing with rice crop have low water requirements compared to rice [75] can follow cotton-wheat cropping system (CWCS). The CWCS is a grain plus cash cropping system which enhance the farmer’s income through cultivation of cotton as an industrial crop and wheat as a component of food security [76]. Sugarcane (*Saccharum sp.*) crop occupies important position in Indian agriculture, as it is the second largest organized agro-industry in the country, next only to textiles. Due to the multifarious use of sugarcane (sugar and by its product) as it can be stand as a good alternative for rice in IPGs. These higher net returns were recorded as sugarcane was with rice in rice- wheat cropping system [77,78]. Both crops are planted at wider placing so; intercropping is possible which generate additional income and efficiently uses the applied inputs.

11. COMPARING ALTERNATE CROPPING SYSTEM FOR THEIR CROP PRODUCTIVITY, ECONOMICS ANALYSIS, WATER AND NUTRIENT PRODUCTIVITY AND SOIL HEALTH

There is an immense scope of diversification of the traditional RWCS without any economic yield loss, rather it improves sustainability. The higher rice equivalent yield was recorded in maize–potato-onion (32.0), summer groundnut-potato-*bajra fodder* (24.7) and maize-potato-summer moong bean (22.9 t/ha) over the RWCS (12.9 t/ha/annum) [77,79]. The more rice equivalent yield in these cropping systems may be due to high yield potential of potato and onion (Chaudhary et al. 2001). Replacement of rice with sugarcane gave higher yield but it at takes 9-12 month to get ready for harvest. Walia et al. [77] shows higher REY in groundnut-*toria*+ *gobhisarson*cropping system over the rice by 29.2%. The cropping system having summer grain/fodder legume or Sesbania as green manure produced significantly higher REY than the rice-wheat system [69]. The diversification rice-wheat system not only provides more productivity and economic yield but, it ensures the efficient use of resources and result in substantial saving of irrigation water. The crops like, maize, soybean, cotton and summer groundnut in rainy season are suitable and remunerative substitute to the nutrient and water exhaustive rice crop. The wheat crop can also be replaced with crops like, Indian mustard, grain pea, sunflower, potato, vegetable pea and onion, as regularly or intermittently [80,81,82]. These types of experiences are similar in tropical areas of Panama according to Olivares, Pitti and Montenegro [83] and Pitti et al. [84].

The inclusion of legumes between the two crops helps in restoring soil health, improve crop productivity and contributes toward cropping systems sustainability [2,72]. Higher water requirement of rice crop, one of the major causesfor replacing the rice in IGPs where rice is mostly cultivated under irrigated condition. Crop diversification can play an important role in reducing the crop irrigation water requirement in the RWCS [75, 85]. So, the crop requires less water demand such as cotton, maize or legumesin summer, monsoon season should be substituting with rice, which help to enhance the water productivity. This water saving is measuring by amount of water applied through irrigation (cm), water productivity (kg grain m^{-3} irrigation water) and system water use efficiency (kg ha mm^{-1}).In many studies founded that, ET losses decreased to an extent when the RWCS wasre placed with cotton–wheat (C–W) or maize–wheat (M–W) as cotton (71 cm) and maize (73.7 cm) have reduced water requirements compared to rice [75,85] and [86]. Cropping system such as groundnut + Gobhi Sarsonand groundnut-potato-pearl millet (F), recorded higher water productivity due to lower water requirement of, pearl millet, sarson and groundnut.

The cropping system of maize-potato-mungbean and maize-potato-onion have higher water productivity was mainly due to higher yield of potato and onion and lower water requirement of maize and mungbean Walia et al. [77]. Adopting the maize-wheat cropping system has higher irrigation water productivity compared with the RWCS. Similarly, soybean–wheat crop rotation has potential for effective management of natural resources [87]. Along with crop productivity and water, other natural resources such as land and energy also taken into consideration while selecting viable crops for substitution of rice in the RWCS. With studying short term significance of crops and cropping system their sustainability index also needs to be studied which is calculated from sustainability index (S.I.). Crops like maize, cotton and groundnut recorded lower sustainability index than rice but difference in sustainability index is marginal.

The substitution with maize, cotton and groundnut-based cropping systems showed high net profit compared to rice-based cropping system [77]. Addition of legume during summer season (green gram and black gram) and fodder crops (Pearl millet and Berseem) increase economic returns due to their low cost of cultivation and short duration. Replacement of rice with pigeon pea also gave more economic net returns as reported by Singh et al. [88]. The inclusion of vegetables in crop system can improve the profitability of the system Samui et al. [89]. The benefits of adding legumes inthe RWCS in terms of yield increase and soil fertility regeneration in the have been well documented [90]. It speeded up the N and P transformation [91,92] and increased root growth and N use efficiency. Organic carbon is an important indicator of soil health, as the maximum reduction of organic carbon was recorded in the rice- wheat cropping system over maize-potato-onion and groundnut-potato-*bajra* (fodder) The more P values in the summer groundnut-potato-*bajra* (fodder) and maize-wheat cropping system over rice- wheatover its initial values.The availableK-status followed the similar trend as observed inavailable P status Roy Bardhan et al. [93] and Walia et al. [94].

The continuous practicing the RWCS, on same piece of land increases the population of grassy weeds (74 m^2)like *Phalaris minor*, which decreased radically in maize-wheat- moongbean, summer groundnut- *toria*+ *gobhisarson* and in the other cropping sequence. The *Phalaris minor* infestation was reduced discernibly which varied from 3 to 12 only as against 36 as in rice-wheat system. Similarly, the case with broadleaf weeds groundnut- *toria*+ *gobhisarson* recorded was lowest broadleaf weed population (10) whereas in the RWCS it was maximum (25). Substitution of forage crop, such as berseem in rice wheat cropping system which help in reducing weed infestation like *Phalaris minor* in succeeding wheat crop [74]. It may be attributed due to the change in the physical conditions of the soils on account of puddling. The addition of legume in crop rotation improvement of soil structure following [91] and help in breaking of the cycle of pests and diseases [94] provides extra yield from the crop sequences.

12. CONCLUSION

The rice wheat cropping system (RWCP) plays the vital role in the achieving food security need of nation. But with continuous adoption of the rice-wheat system, threaten the sustainability of production system. It causes many serious problems and environmental threats, *viz.* over exploitation of ground water which leads to decline water table, degradation of soil health. The intensive use of chemical fertilizers and pesticide which enhanced groundwater pollution and developed resistance against weeds and insect-pest, crop residue burning, resulted into the environmental pollution, enhanced greenhouse gas emissions. There is an urgent need to sustain the crop production system. The crop diversification found to be the sustainable way of crop production by inclusion of various crops which are more remunerative, less risky, eco-friendly, restoring soil fertility and improving soil health and with efficient utilization of resources. Substitution of rice- wheat cropping with other crops*viz.* cereals (maize), pulses (mung bean, green gramand pigeon pea) and oilseed (soybean and Sunflower), fodder (Berseem and Pearlmillet) vegetable crops cash crops (cotton and sugarcane). It improves crop productivity, restoring soil health, reducing weed infestation and help in breaking of the cycle of pests and diseasesand increases economic returns of farmers. The crop diversification contributes toward sustainable cropping systems with better resources use efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nawaz A, Farooq M, Nadeem F, Siddique KHM, Lal R. Rice– wheat cropping systems in South Asia: issues, options and opportunities. Crop Pasture Sci. 2019; 70:395.
   DOI:https ://doi.org/10.1071/cp183 83
2. Timsina J, Connor DJ. Productivity and management of rice– wheat cropping systems: issues and challenges. Field Crops Res. 2001;69(2):93–132.
3. Bhatt R, Hossain A, Busari MA, Meena RS. Water footprints in rice-based systems of South Asia. In: Barnarjee A, Meena RS, Jhariya MK (eds) Footprints in Agroecosystem. Springer, Singapore. 2020;272–308.
   DOI:https//doi.org/10.1007/978-981-15-9496 0_9.
4. Reddy BN, Suresh G. Crop diversification with oilseed crops for maximizing productivity, profitability and resource conservation. Indian Journal of Agronomy. 2009;54(2):206–214.
5. Chauhan BS, Mahajany G, Sardanay V, Timsina J, Jat ML. Productivity and sustainability of the rice-wheat cropping system in the indo-gangetic plains of the indian subcontinent: Problems, opportunities, and strategies. Advances in Agronomy. 2013;117: 315–369.
6. Humphreys E, Kukal SS, Christen EW, Hira GS, Singh B, Sudhir Yadav, Sharma RK. Halting the ground water decline in north-west India-which crop technologies will be winners?. Advances in Agronomy. 2010;109:156–199,
   DOI:http://dx.doi.org/10.1016/S0065-2113(10)09005-X.Intensification of potato production in rice-based cropping systems: a rapid rural appraisal in West Bengal, (In) *Impacton a Changing World.* (International Potato Centre Programme Report 1997-98:205–212.
7. Hira GS, Jalota SK, Arora VK. Efficient management of water resources for sustainable cropping in Punjab. Research Bulletin, Department of Soils, Punjab Agricultural University, Ludhiana. 2004;20.
8. Bhatt R, Kukal SS. Direct seeded rice in South Asia. In: E Lichtfouse (ed.) Sustain Agriculture Reviews. 2015a;18:217–252.
9. Bhatt R, Kukal SS. Delineating soil moisture dynamics as affected by tillage in wheat, rice and establishment methods during intervening period. J Appl Nat Sci. 2015b;7(1):364–368.
10. Bhatt R, Kukal SS. Soil moisture dynamics during intervening period in rice–Wheat sequence as affected by different tillage methods at Ludhiana, Punjab. India Soil Environ. 2015c;34(1):82–88.
11. Aggarwal GC, Sidhu AS, Sekhon NK, Sandhu KS, Sur HS. Puddling and N management effects on crop response in a rice– wheat cropping system. Soil and Tillage Research. 1995;36:129–139.
12. Bhatt R, Kukal SS, Busari MA, Arora S, Yadav M. Sustainability issues on rice–wheat cropping system. International Soil and Water Conservation Research. 2016; 4(1):64–74.
13. Roper M, Ward P, Keulen A, Hill J. Under no tillage and stubble retention, soil water content and crop grow there poorly related to soil water repellency. Soil and Tillage Research. 2013;126:143–150.
14. Das A, Lal R, Patel D, Idapuganti R, Layek, Ngachan S, Ghosh P, Bordoloi J, Kumar M. Effects of tillage and biomass on soil quality and productivity of low land rice cultivation by small scale farmers in North Eastern India. Soil Tillage and Research. 2014;143:50–58.

15. Singh P, Singh G, Sodhi GPS. Energy auditing and optimization approach for improving energy efficiency of rice cultivation in south-western Punjab, India. Energy. 2019a;174:269–279.
16. Singh P, Singh G, Sodhi GPS. Applying DEA optimization approach for energy auditing in wheat cultivation under rice–Wheat and cotton-wheat cropping systems in north-western India. Energy. 2019b; 181:18–28.
17. Ladha JK, Kumar V, Alam MM, Sharma S, Gathala M, Chandna P. Integrating crop and resource management technologies for enhanced productivity, profitability, and sustainability of the rice–Wheat system in South Asia. In: Ladha JK, Singh Y, Erenstein O, Hardy B (eds). Integrated crop and resource management in the rice wheat system of South Asia'. Los Banos; 2009.
18. Saini J, Bhatt R. Global warming - causes, impacts and mitigation strategies in agriculture. Curr J Appl Sci Technol. 2020;39(7):93–107.
19. Singh P, Benbi DK. Nutrient management impacts on net ecosystem carbon budget and energy flow nexus in intensively cultivated cropland ecosystems of north-western India. Paddy Water Environ. 2020a;18(4):697–715.
20. Kumar A, Yadav DS. Effect of long-term fertilizer on soil and yield under rice-wheat cropping system. J Indian Soc Soil Sci. 1993;41:178–180.
21. Olivares B, Hernandez R, Arias A, Molina JC, Pereira Y. Eco-territorial adaptability of tomato crops for sustainable agricultural production in Carabobo, Venezuela. Idesia. 2020;38(2):95-102.
DOI: https://n9.cl/6muqd
22. Bhowmick MK, Duary B, Biswas PK. Crop diversification through oilseeds in Eastern India. In: Madhusudan Ghosh, Debashis Sarkar, Bidhan Chandra Roy (Ed) Diversification of Agriculture in Eastern India, Springer, New Delhi. 2005;109–130.
23. Bhatt R, Kukal SS, Busari MA, Arora S, Yadav M. Sustainability issues on rice–wheat cropping system. International Soil and Water Conservation Research. 2016; 4(1):64–74.
24. Hossain A, Sarkar S, Barman M, Majumder D, Saha S, Bhatt R, Islam M, Meena RS. Advance technological management of intensive rice–Wheat systems of South-Asia. In: A. Barnarjee, RS Meena, MK Jhariya (eds) Food and environmental security. Accepted in Springer Book, "Footprints in Agroecosystem"; 2020.
25. Olivares B. Description of soil management in agricultural production systems of the Hamaca sector of Anzoátegui, Venezuela. La Granja: Revista de Ciencias de la Vida. 2016;23(1):14–24. DOI:https://doi.org/10.17163/lgr.n23.2016.02
26. Olivares B, Araya-Alman M, Acevedo-Opazo C, et al. Relationship between soil properties and banana productivity in the two main cultivation areas in Venezuela. J Soil Sci Plant Nutr. 2020;20(3):2512-2524. DOI:https://doi.org/10.1007/s42729-020-00317-8
27. Mondal M, Kumar S, Haris AA, Dwivedi SK, Bhatt BP, Mishra JS. Effect of different rice establishment methods on soil physical properties in drought-prone, rainfed lowlands of Bihar, India. Soil Research. 2016;54 (8):997–1006.
28. Sapkota TB, Jat RK, Singh RG, Jat ML, Stirling CM, Jat MK, Bijarniya D, Kumar M, Singh Y, Saharawat YS, Gupta RK. Soil organic carbon changes after seven years of conservation agriculture in a rice–wheat system of the eastern Indo-Gangetic Plains. Soil Use Management. 2017;33: 81–89.
29. Dobermann A, Fairhurst TH. Rice straw management. Better Crops Int 16:7–9 Epule ET, Peng C, MafanyGangwar, B. and Prasad, K. 2005. Cropping system management for mitigation of second-generation problems in agriculture. Indian Journal of Agricultural Science. 2002; 75(2):65–78.
30. Singh G, Singh P, Sodhi GPS, Tiwari D. Adoption status of rice residue management technologies in South-Western Punjab. Ind J Ext Edu. 2020; 56:76–82.
31. Gill JS. Land use, conservation management and development of land resources of Punjab. Chandigarh, Punjab: Report of Department of Soil Conservation and Engineering; 1992.
32. Olivares B, Lobo D, Verbist K. Application of the USLE model in erosion plots under soil and water conservation practices in San Pedro de Melipilla, Chile.

RevistaCiencia e Ingeniería. 2015;36(1):3-10.
DOI:https://www.redalyc.org/pdf/5075/507550627001.pdf
33. Olivares B, Verbist K, Lobo D, Vargas R, Silva O. Evaluation of the USLE model to estimate water erosion in an Alfisol. Journal of Soil Science and Plant Nutrition of Chile. 2011;11(2):71-84. DOI:http://dx.doi.org/10.4067/S0718-95162011000200007
34. Biswas BC, Tewatia RK. Nutrient balance in Agro-ClimaticregionsofIndia-anoverview. Fertilizer News. 1991;36:13–17.
35. Tiwari KN, Sharma DN, Tripathi SK. Alt affected soils of Uttar Pradesh, their reclamation and management (pp. 1–34) Kanpur, India: C.S. Azad University of Agriculture and Technology. 1989;1–34.
36. Katyal JC. Soil fertility management—a key to prevent desertification. Indian Society of Soil Science. 2003;51:378–387.
37. Chatterjee C, Sinha P, Nautical, S, Aggarwal C, Sharma CP. Metabolic changes associated with boron-calcium interactionin Maize. Soil Science and Plant Nutrition. 1987;33:607–617.
38. Singh KK, Jat AS, Sharma SK. Improving productivity and profitability of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system through tillage and planting management. Indian Journal of Agricultural Sciences. 2005;75:396–399.
39. Dhillon BS, Kataria P, Dhillon PK. National food security vis-àvis sustainability of agriculture in high crop productivity regions. Curr Sci. 2010;98:33–36.
40. Mahajan G, Chauhan BS, Johnson DE. Weed management in aerobic rice in Northwestern Indo-Gangetic Plains. J Crop Improv. 2009;23(4):366–382.
41. Mahajan G, Chauhan BS. Effects of planting pattern and cultivar on weed and crop growth in aerobic rice system. Weed Technol. 2011;25(4):521–525.
42. Bajwa GS. Nitrate pollution of ground water under different systems of land management in Punjab .Published In Proceedings of the of Agricultural Science Congress, National Academy of Agricultural Sciences: New Delhi. 1993; 223–230.
43. Sidhu BS, Beri V. Effect of crop residue management on the yields of different crops and on soil properties. Biol Wastes. 2005;27:15–27.
44. Beri V, Sidhu BS, Gupta AP, Tiwari RC, Pareek RP, Rupela OP, Khera R, Singh J. Organic resources of a part of indo-gangetic plain and their utilization. Department of Soils, Punjab Agricultural University, Ludhiana. 2003;93.
45. Singh SS, Singh AK, Sundaram PK. Agrotechnological options for upscaling agricultural productivity in eastern Indo Gangetic Plains under impending climate change situations: a Review. J Agric. 2014;1(2):55–65.
46. Yadvinder -Singh, Singh M, Sidhu HS, Khanna PK, Kapoor S, Jain AK, Singh AK, Sidhu SK, Singh SK, Singh A, Chaudhary DP, Minhas PS. Options for effective utilization of crop residues. Research Bulletin No 3/2010, Director of Research, Punjab Agricultural University, Ludhiana. 2010; 32.
47. NASA. Innovative viable solution to rice residue burning in rice–wheat cropping system through concurrent use of super; 2017.
48. Yadvinder, Singh, Bijay, Singh, Timsina J. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. Advances in Agronomy. 2005;85:269–407.
49. Jain N, Bhatia A, Pathak H. Emission of air pollutants from crop residue burning in India. Aerosol Air Quality Research. 2014;14:422–430.
50. Chauhan BS, Opeña J. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. Field Crops Res. 2012;137:56–69.
51. Chauhan BS, Mahajan G, Sardana V, Timsina J, Jat ML. Productivity and sustainability of the rice-wheat cropping system in indo-Gangetic plains of the Indian subcontinent: Problems, opportunities' and strategies. Advances in Agronomy. 2012;117:315–369.
52. Mahajan G, Chauhan BS. The role of cultivars in managing weeds in dry-seeded rice production systems. Crop Protect. 2013;49:52–57.
53. Singh M, Bhullar MS, Chauhan BS. Influence of tillage, cover cropping, and herbicides on weeds and productivity of dry directseeded rice. Soil Till Res. 2015a; 147:39–49.

54. Singh M, Bhullar MS, Chauhan BS. Seed bank dynamics and emergence pattern of weeds as affected by tillage systems in dry direct-seeded rice. Crop Prod. 2015b; 67:168–177.
55. Kumar P, Singh O, Ahlawat IPS. Weed dynamics, growth and yield of wheat crop as influenced by different tillage and herbicide management under rice–Wheat cropping system. J Agric. 2014;1(3):161–167.
56. Vrbničanin S, Pavlović D, Božić D. Weed resistance to herbicides. In: Pacanoski Z (ed) Herbicide resistance in weeds and crops. Intech Open; 2017.
DOI: https ://doi.org/10.5772/67979 s
57. Tranel PJ, Wright TR. Resistance of weeds to ALS-inhibiting herbicides: what have we learned? Weed Sci. 2002;50(6):700–712.
58. Chhokar RS, Sharma RK, Garg R, Sharma I. Metsulfuron resistance in *Rumex dentatus*: Wheat barley Newsletter. 2013;7:11.
59. Dhanda S, Chaudhary A, Kaur S, Bhullar, MS. Herbicide resistance in Rumexdentatus against metsulfuron herbicide in Punjab and Haryana, India. Indian Journal of Weed Science. 2020;52(3):259-264.
60. Singh B, Humphreys E, Gaydon DS, Yadav S. Options for increasing the productivity of the rice–wheat system of north west India while reducing groundwater depletion. Part 2. Is conservation agriculture the answer? Field Crop Research. 2015c;173; 81-94.
61. Shah, TR, Prasad, K, Kumar P. Maize- A potential source of human nutrition and health: A review. Cogent Food and Agriculture. 2016;2:1-9.
DOI:https://doi.org/10.1080/23311932.201 6 .11 66995
62. Singh A, Kang JS, Hundal RK, Singh H. Research needs and direction for sustainability of rice based cropping system. Discovery Nature. 2012;1(2):23–35.
63. Dass A, Kumar A, Jat SL, Parihar CM, Singh AK, Chikkappa GK, Jat ML. Maize hold potential for diversification and livelihood security. Indian Journal of Agronomy. 2012;57:86–91.
64. Bertorelli M, Olivares BO. Population fluctuation of *Spodopterafrugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in sorghum cultivation in Southern Anzoátegui, Venezuela. Journal of Agriculture University of Puerto Rico. 2020;104(1):1-16.
DOI:https://doi.org/10.46429/jaupr.v104i1.18283
65. Olivares B, Hernández R, Arias A, Molina JC, Pereira Y. Zonificación agroclimática del cultivo de maíz para la sostenibilidad de la producción agrícola en Carabobo, Venezuela. Revista Universitaria de Geografía. 2018ª;27(2):139-159.
DOI:https://n9.cl/ah6c
66. Olivares B, Cortez A, Parra R, Lobo D, Rodríguez MF, Rey JC. Evaluation of agricultural vulnerability to drought weather in different locations of Venezuela. Rev. Fac. Agron. (LUZ). 2017;34(1):103-129. DOI: https://n9.cl/hc5xs
67. Olivares B, Torrealba J, Caraballo L. Variability of the precipitation regime in the period 1990-2009 in the location of El Tigre, Anzoátegui state, Venezuela. Rev. Fac. Agron. (LUZ). 2013;30 (1):19-32.
DOI: https://n9.cl/mic0l
68. Cortez A, Rodríguez MF, Rey JC, Ovalles F, González W, Parra R, Olivares B, Marquina J. Variabilidad espacio temporal de la precipitación en el estado Guárico, Venezuela. Rev. Fac. Agron. (LUZ). 2016;33(3):292-310.
Doi: https://n9.cl/pmdck
69. Singh RK, Bohra JS, Nath T, Singh Y, Singh K. Integrated assessment of diversification of rice-wheat cropping system inIndo-Gangetic plain. Archives of Agronomy and Soil Science. 2011;57(5): 489–506.
70. Davari, MR, Sharma, SN, Mirzakhani, M. Effect of cropping systems and crop residue incorporation on production and properties of soil in an organic agro-ecosystem. Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems. 2012; 28(3):206–222.
DOI: 10.1080/01448765.2012.735005.
71. Johansen, C, Duxbury JM, Virmani, SM, Gowda CLL, Pande S, Joshi PK. Introduction and background. In: ICRISAT and Cornell University (Eds.) Legumes in rice-wheat cropping system of Indo-Gangetic plain-Constraints and opportunity. 2000;1–4.
72. Arora S, Bhatt R, Somani LL. Handbook of soil health and water management, vol 313. Publisher Agrotech Publishing

Academy Udaipur, Udaipur. 2020;1–550.

73. Chaudhary VP, Gangwar B, Pandey DK, Gangwar KS. Energy auditing of diversified rice–wheat cropping systems in Indo-gangatic plains. Energy. 2009;34(9):1091–1096.
74. Tripathi SC, Mongia AD, Chauhan DS, Sharma RK, Kharub AS, Chhokar RS, Shoran J. Bed planting: A new technique to diversify/ intensify rice-wheat system in India. In: Fischer, R.A., (Ed.), New. 2004; 2(9):125–138.
75. Jalota SK, Arora VK. Model-based assessment of water balance components under different cropping systems in north-west India. Agric Water Manag. 2002; 57:75–87.
    DOI:https://doi.org/10.1016/ S0378 - 3774(02)00049 -5
76. Mayee CD, Monga D, Dhillon PP, Nehra PL, Pundhir P. Introduction. In: Cotton-wheat production system in south Asia- A success story. 2008;1–2.
77. Walia SS, Gill MS, Bhusan B, Phutela RP, Aulakh CS. Alternate cropping system to rice (*Oryza sativa*)-wheat (*Triticum aestivum*) for Punjab. Indian Journal of Agronomy. 2011;56(1):20–27.
78. Singh R, Singh B, Patidar M. Effect of preceding crops and nutrient management on productivity of Wheat (*Triticum aestivum*) based cropping system in arid region. Indian Journal of Agronomy. 2008; 53(4):267–272.
79. Khaurb, AS, Chauhan, DS, Sharma, RK, Chhokar RS, Tripathi SC. Diversification of rice (*Oryza sativa*) – wheat (*Triticum aestivum*) system for improving soil fertility and productivity. Indian J. Agron. 2003; 48(3):149–152.
80. Gill MS, Ahlawat IPS. Crop diversification-its role towards sustainability and profitability. Indian J. Fertilizer; 2006.
81. Olivares B, Hernández R. Ecoterritorial sectorization for the sustainable agricultural production of potato (*Solanum tuberosum* L.) in Carabobo, Venezuela. Agricultural Science and Technology. 2019;20(2):339-354.
82. Olivares B, Hernández R, Arias A, Molina, JC, Pereira Y. Identificación de zonas agroclimáticas potenciales para producción de cebolla (*Allium cepa* L.) en Carabobo, Venezuela. Journal of the Selva Andina Biosphere. 2018;6(2):70-82. DOI: https://n9.cl/mya5e
83. Olivares B, Pitti J., Montenegro E. Socioeconomic characterization of Bocas del Toro in Panama: an application of multivariate techniques. Revista Brasileira de Gestao e Desenvolvimento Regional. 2020;16(3):59-71. Doi:
    https://n9.cl/1dj6
84. Pitti JE, Cabrigot M, Quintero E. Ecoemprendimiento turístico: Una estrategia de economía aplicada hacia el desarrollo sostenible en territorios indígenas de Panamá. Port Louis, Mauritius: Editorial Académica Española; 2019.
85. Arora VK, Jalota SK, Singh KB. Managing water crisis for sustainable crop productivity in Punjab. J Res Punjab Agric Univ. 2008;45:17–2.
86. Gathala MK, Ladha JK, Kumar V, Saharawat YS, Kumar V, Sharma PK, Sharma S, Pathak H. Tillage and crop establishment affects sustainability of South Asian rice–Wheat system. Agron J. 2011;103(4):961–971.
87. Ram H, Singh Y, Saini KS, Kler DS, Timsina J. Tillage and planting methods effects on yield, water use efficiency and profitability of soybean–wheat system on a loamy sand soil. Exp Agric. 2013; 49(4):524–542.
88. Singh VK, Dwivedi BS, Shukla AK, Chauhan YS, Yadav RL. Diversification of rice with Pigeon pea in rice – wheat cropping system on a Typic Ustochrept: effect on soil fertility, yield and nutrient use efficiency. Field Crop Research. 2005; 92(1):85–105. Straw management system-fitted combines and turbo happy seeder. Policy Brief No. 2, National Academy of Agricultural Sciences, New Delhi. p 16.
89. Samui RC, Kundu AL, Majumder D, Mani, PK, Sahu PK. Diversification of rice *Oryza sativa*)-based cropping system in new alluvial zone of West Bengal. Indian J. Agron. 2004;49(2):71–73.
90. Singh Y, Khind CS, Singh B. Efficient management of leguminous green manures in wetland rice. Adv Agron. 1991; 45:135–189.
91. Wani SP, Rupela OP, Lee KK. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. Plant Soil. 1995;174:29–49.

92. Kannaiyan S. Integrated nutrient management strategies in wetland rice eco-system. In: Kannaiyan S, Thiyagarajan TM, Mathan KK, Savithiri P, Selvakumari G, Murugappan V, editors. Theme papers on integrated nutrient management. Tamil Nadu: Tamil Nadu Agricultural University, and Department of Agriculture. 2000; 1–20.
93. Roy Bardhan SK, Walker T, Khatana VS, Saha NK, Verma VS, Kadian MS, Haverkort AJ, Bowen W. Intensification of potatoes in rice- based cropping system: A rapid rural appraisal in west Bengal; 1999.
94. Sanford JO, Hairston JE. Effects of N fertilization on yield, growth and extraction of water by wheat following soybean and sorghum. Agron J. 1984;76:623–627.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/67868