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Sustainability issues in the rice-wheat cropping system (RWCS)

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Abstract

Rice-wheat cropping systems (RWCS) are labour-intensive, water-intensive, capital-intensive, and energy-intensive, and have grown less viable as the supply of these resources has decreased. This might be compounded by deterioration of soil structure, dwindling subterranean water, and lower land and water productivity, all of which pose a danger to the region's long-term viability and profitability. A paradigm shift is necessary to improve the profits, production, and long-term viability of this sequence. For this objective, scientists suggested a variety of resource-conserving technologies (RCTs) such as zero-tillage, laser-levelling, irrigation based on soil matric potential, bed planting, direct seeding, rice mechanical transplanting, and crop diversification. The various technologies are site specific, and soil texture and agro-climatic factors must be examined before using any particular RCT for a certain region. A single approach/RCT may not be sufficient to address the looming problem of producing more food grains with limited water and land. As a result, an integrated strategy is required. However, before implementing any strategy, several RWCS-related concerns must be identified, examined, and addressed holistically. In this review, an attempt was made to highlight various issues that have arisen as a result of the region's intensive rice-wheat cropping sequence, which must be considered when framing and implementing any integrated approach/project such as conservation agriculture to improve the region's RWCS production, profits, and sustainability.

Keywords: Sustainability, rice-wheat, labour-intensive, water-intensive

Introduction

RWCS is the world's largest agricultural production system, covering approximately 12.3 million hectares in India, 0.5 million hectares in Nepal, 2.2 million hectares in Pakistan, and 0.8 million hectares in Bangladesh, with around 85 percent of this land falling within the Indo-Gangetic plains (IGP) (Ladha *et al*. 2003; Timsina & Connor 2001) [23]. The IGP region of India has RWCS spread across avast area from Punjab in the Northwest to East up to West Bengal (Singh, Jat & Sharma, 2005). With yield stagnation (Ladha *et al*. 2003; Busari, Kukal, Kaur, Bhatt & Dulazi, 2015) [6, 23], declining under groundwater table (Humphreys *et al*. 2010; Hira, Jalota & Arora, 2004), unattended intervening periods (Bhatt and Kukal 2014 a, b; Bhatt and Kukal 2015 a, b, c) [6], and soil degradation (Bhatt and Kukal 2015) [6], (Bhandari *et al*. 2002) pollution in the atmosphere and atmospheric pollution (Bijay, Shah, Beebout, Yadvinder & Buresh, 2008). Rice is traditionally grown in the region by repeated wet tillage (Puddling) followed by transplantation of the seedlings into the puddled soil, whereas wheat is traditionally introduced (in rice residue burned lands) by broadcasting/drilling seed following disking, tilling, and planking processes (Bhatt, 2015) [6]. Seed bed preparation operations oxidise previously hidden organic matter and split macro-aggregates into micro-aggregates, affecting soil characteristics negatively (Roper, Ward, Keulen & Hill, 2013; Das *et al*. 2014). Furthermore, soil disturbance caused by conventional tillage causes the soil to act as a source rather than a sink of pollutants in the atmosphere, making it non-sustainable and environmentally friendly (Busari *et al*. 2015). Improved RWCS production should be a top priority to keep up with India's population growth, which is expected to rise from 1.12 billion in 2008 to 1.35 billion by 2025. (UNEP, 2008). However, the farmers' traditional methods for planting wheat and rice, which are based on their indigenous knowledge, are water, money, and energy intensive, and result in a slew of problems that pose a severe danger to the sustainability of agriculture. This article aims to highlight almost all of the sustainability challenges that have arisen as a result of intense RWCS farming in order to rescue the region without degrading the God-given resources of soil and water.

Issues related with rice-wheat cropping system

The following challenges arise as a result of the indigenous rice-wheat planting system. Considering these concerns as a danger to sustainable and profitable agriculture, an endeavour is being made to examine the issues under the following topics in order for scientists to develop, test, and promote alternate wheat and rice establishment techniques/RCTs in the region.

Ecological issues

Declining underground water table in India

More than a quarter of the total global water consumption (Tyagi, Datta & Singh, 2012) [31] is used here, making it the world's largest ground water user (230 km^3 yr^{-1}). Rather than being a big water consumer, the agricultural sector appears to be losing ground since water allotted for irrigation is expected to diminish in the future years (Singh, Kundu & Bandyopadhyay, 2010) [27]. Irrigation is a basic need for the agriculture sector, but its unjudicious use results in large consumption of green and blue water required for this sector (Rost *et al*. 2008; Döll *et al*. 2012). Irrigation is a basic need for the agriculture sector, but its unjudicious use results in large consumption of green and blue water required for this sector (Gardner-Outlaw & Engelman, 1997). Before 150 years, water came directly from the mountains and into the sea, without significant infiltration into the earth, according to his perspective. Six headworks were framed and water supplied to the agri-cultural field for irrigation from 100 years ago (1859-1960) with the development of the multi-development river project.

Diverse weed flora

The importance of a diverse weed flora and excessive weed pressure in the path to sustainable agriculture cannot be overstated. The weed flora simplified with grasses as a result of intense rice-wheat sequence cropping. Weeds fight for light, water, and nutrients with the primary plants, lowering the overall and overall productivity of the system. Weeds are a key biotic limitation to sustainable agriculture in Asia, with extreme cases resulting in full grain output reductions. Because there is no puddling processes involved with dry direct seeded rice, it is thought to have greater water productivity. However, because the early flush of weeds in dry direct-seeded rice is not controlled by flooding, yield loss is more likely than in puddled transplanted rice (Rao, John-son, Sivaprasad, Ladha & Mortimer, 2007; Chauhan, 2012) [9, 22].

Insect-borne diseases and pests are on the rise. Wheat and rice crops are both grown in a lush environment. Green crops with greater N-fertilizer doses and damp circumstances due to infrequent irrigations are a haven for insect-pest and disease outbreaks. Furthermore, farmers acting on the advice of dealers adds to the system's complexity, which is worsened by the monoculture system's influence. Disease outbreaks and insect-pest attacks are mostly to blame for decreased water and land productivity, and are seen as a severe concern on the road to sustainable agriculture. From a farmer's perspective, the factor productivity is the decline in fact or productivity (Table4). Yields are decreasing or staying the same. It was discovered that when the cost of cultivation increased, the efficiency of input usage declined, increasing the danger probability even more. Natural disasters, such as floods and draughts, may force farmers to make difficult decisions. Since the previous few decades, new breeds of insect pests/diseases (which are more resistant to current insecticides) have emerged.

Agriculture and conservation Conservation Agriculture (CA), according to the FAO, is a farming strategy that can prevent the loss of arable land while also restoring degraded soils. Plant species are diverse, a permanent soil cover is maintained, and soil disturbances are kept to a minimum. CA is environmentally benign, and it emits less carbon than conventional agriculture since it recycles nutrients, produces less soil damage, takes less water, and promotes water usage efficiency. According to a study, the productivity and net returns from the basmati Rice-Wheat Cropping System under CA were 36 percent and 43 percent greater than the conventional system, with reduced labour usage per area, lower input costs, and less irrigation in terms of ponding time, respectively (Jat *et al*.). Farmers noticed early crop maturity, with 90% of wheat and 100% of rice, in the CA practise of the same experiment (Pokharel *et al*.). In the same trial, farmers who utilised Zero Tillage reduced the amount of seed used for wheat production from 200kg ha-1 to 100kg ha-1.

Reduced tillage or zero tillage one of the most important aspects of conservation agriculture is zero tillage. Seeds are immediately sown to require depth and spacing using a zero till seed cum fertiliser drill or other heavy seeded based on the presence or absence of crop residue, also known as conservation tillage (FAO). This approach not only preserves soil structure, but also enhances soil nutrients, preserves soil microorganisms, and reduces soil moisture loss, all of which contribute to increased production. When compared to farmers' practise, the productivity of zero tillage and reduced tillage was greater by 780 kg/ha and 454 kg/ha, respectively, while the cost of production for sowing was lower by Rs 1160/ha and Rs 1510/ha (Jat *et al*.). When compared to traditional farming, zero tillage with residue recycling boosted soil organic content by 21%. (Jat *et al*. 2014) [21]. In a zero-tillage system, weed emergence is rather modest. In a rice field, traditional technique involves two or three times hard tillage followed by puddling, which alters the soil's physical and chemical qualities. Puddling at a depth of 10-12 cm results in the formation of a sub-surface compact layer at 14-20 cm, which persists even in post-rice wheat seedbed preparation (Kukal and Aggarwal, 2003).

Wheat grain yields are reduced as a result of this. As a result, extending the zero-tillage practise to the farmer's field is critical for enhancing productivity and ensuring long-term sustainability. Unpuddled transplanted rice followed by zero tillage wheat was shown to be beneficial in Sunsari, with a B:C ratio of 2.96 and grain production of 8.11 tonne per ha, but the B:C ratio in traditional Rice-Wheat Cropping was only 2.27. (Pokharel *et al*. 2018). These findings suggest that zero tillage is not only environmentally friendly, but also more productive and can readily replace the traditional tillage technique. CA produced substantially more grain (4766 kg ha-1) than traditional agriculture (4106 kg ha-1) (Marahatta *et al*. 2017). 3.3.2 Nutrient Management Integrated Long-term usage of single organic manures poses a risk of unsustainable output, while a heavy reliance on chemical fertilisers degrades soil quality (Pandey *et al*. 1998). By designing farming methods that increase soil health and food security, Integrated Nutrient Management ensures sustainability (Sharma *et al*. 2015). A group of researchers proposed using FYM to preserve soil fertility and recommended 10 t/ha FYM + 50 kg N/ha in paddy, whereas 100-30-30 kg N: P2O5: K2O was recommended for the sustainability of the Rice-Wheat Cropping System (Shrestha *et al*. 2015). Farmers are now experiencing a drop in production even after spraying NPK. The use of balanced fertiliser alone does not maintain soil fertility over time, but combining it with FYM increases crop output and improves soil physical qualities (Kabeerathumma *et al*. 1993; Lal *et al*. 1990). Potassium was identified as the limiting component for long-term yield by a group of researchers (Rawal *et al*. 2017). Soil organic matter, together with potassium fertiliser and crop biomass, is critical for maintaining soil pH and nutrient availability, therefore applying FYM and adding potassium fertiliser and crop biomass boosts long-term yields (Shrestha, 2015).

Alternate wetting and drying (AWD)

The continual cycle of flooding, draining, and re-flooding in line with crop stage and vital water requirement to maintain optimum water level in all stages of crop life is known as alternate drying and wetting (AWD) (Lamsal and Khadka, 2019). The rice field is first dried until only enough water remains for crop growth. The water level in the field is measured with a tensiometer. When the water level falls below the ideal, reflooding is done. The field is wet in all stages of crop growth except flowering (Lamsal and Khadka, 2019). Although AWD plots got more water, the trial on dry season rice in Nepal's middle Terai found no significant difference in yield between treatment plots. When compared to conventional irrigation, a similar experiment found 27.3 percent less water usage with no yield loss (Djaman *et al*. 2018). AWD system improves tillering, root growth, and helps reduce CH4 emissions from rice fields by a large amount, in addition to water use efficiency. AWD-induced rhizosphere drying can also modify plant hormone signalling and increase grain filling rate, especially in inferior spikelets, resulting in increased plant water usage efficiency (Zhang *et al*. 2010, 2012; Tabbal *et al*. 2002; Davies *et al*. 2011). A key impediment to AWD's widespread adoption is that its yield effects (both positive and negative) differ significantly across soils, climates, cultivars, and other factors. Mulching and Planting in the Beds Furrow diking method is important in bed planting and mulching in semi-arid regions like Nepal, where rainfall intensity is strong but duration is short (Lyle and Dixon, 1977). Mulching decreases weed stress and soil moisture loss while also providing nutrients. The bed planting system is used for improved water and nutrient efficiency, lower seed rate, better plant stands, pre-plant weed control, mechanical weed control between the beds early in the crop cycle, reduced herbicide dependence, lower hand weeding, less crop logging, and more crop diversification opportunities (Hobbs and Giri, 1997). According to a study, bed planting yielded 3524 kg/ha greater than farmer practise (2996 kg/ha), and the overall annual grain yield was increased by more than 1100 kg/ha in the bed planting technique with mulching (Tripathi *et al*. 2002). The mean annual total grain yield increased by more than 600 kg/ha on bed planting of the rice-wheat-mungbean system compared to flat planting (Sah *et al*. 2011) [22]. According to the same report, bed mulch contributed to an increase in total grain output of more than 1100 kg/ha. However, bed planting has a greater production cost for site preparation and sowing, which can be decreased by using permanent beds technology. Under permanent bed planting in RWCs, participatory research conducted in farmers' fields in hilly regions was successful, reducing production costs by 20-25 percent over conventional approaches (Bhattarai *et al*. 2004). 3.3.5 Cropping Pattern Variation in cropping patterns changes the rhizosphere-affected soil area by replacing depleted nutrients in each cropping season. When planted in rotation with the legume, *Bradyrhizobium* sp. and *Herbaspirillum* sp. invade the rice roots, boosting rice growth and availability of plant nutrients, particularly nitrogen and phosphorus (Zhou *et al*. 2014). Legumes improve nutrient availability, soil structure, disease incidence, and mycorrhizal colonisation in crop rotation, in addition to biological nitrogen fixation (Cupina, 2014; Wani *et al*. 1995). Because enhanced varieties with higher yields are favoured, the higher nitrogen requirements of high yielding rice cultivars could be satisfied by legume, resulting in increased growth and yield (Yadvinder-Singh *et al*. 2004). Grain legumes in crop rotation can provide two advantages: first, they can add nutrients to the soil, and second, they can provide additional income and a source of vegetable protein (Gathala *et al*. 2014; Timsina *et al*. 2006; Yadvinder-Singh *et al*. 2004) [21]. The additional nitrogen given by legumes improves grain output while also lowers production costs by reducing the usage of chemical fertiliser and delivering a greater economic return to farmers without causing environmental damage.

Extension of CA to farmer practice

There is no clear line between Conservation Agriculture (CA) and Climate Smart Agriculture (CSA). However, the CA techniques have been renamed CSA, and Nepal has become more familiar with the concept of sustainability as CSA. Climate Smart Villages (CSVs), established by ICIMOD in collaboration with Environment and Agricultural Policy Research, Extension and Development, are a multi-stakeholder approach practise at the local level to enhance CSA. According to a group of researchers, CSA technology can be scaled up in regions with similar characteristics, such as Nawalparasi, the hills and high hills area of Kaski, and Lamjung, where it was tested and evaluated in pilot projects (Khatri-Chhetri *et al*. 2017). DADO Sunsari has aided the spread of CA technologies for wheat by policy and increased farmer visits to demonstration plots, as well as training programmes and the distribution of CA technology flyers and pamphlets. There were 250 farmers with 350 hectares employing ZT in various cereal crops, according to the report (Pokharel *et al*. 2018). CSISA has been promoting CA-based technology in rice-based systems in the eastern and mid Terai (Karki and Shrestha, 2015).

Effect of climate smart agricultural practices (CSAPs) on growth and yield of rice

Plants grown in damp soil grew taller, had more dry matter, and had more tiller density than transplanted rice (Sarkar *et al*. 2003). Choudhary (2016) [10] found that ZT DSR treatments produced the tallest plants at harvest, while puddled transplanted rice produced the shortest. At all growth phases, according to Yadav *et al*. (2011), the number of tillers per m2 and dry matter accumulation were considerably higher with DSR than PTR. Mahajan *et al*. (2011) found that aerobic DSR and standard puddled transplanted rice yielded equivalent grain yields. In contrary to the above statement, Akhgari and Kaviani (2011) [30] found that transplanted rice yields higher than DSR. They also stated that a lower yield is balanced by a decrease in production. They discovered that while DSR had over 150 percent more panicles per unit area than PTR, grain weight per panicle was higher in the transplanted crop. Under DSR, the compensation of various yield components resulted in grain yields that were statistically similar.

Precision land levelling (PLL) increased rice yields by 4.3 percent over traditional land levelling, according to Kaur *et al*. (2012). (TLL). At the same level of variety and fertiliser application, Rickman (2002) found that PLL increased rice output by 24 percent, or 530 kg ha^{-1}. Wheat Zero Tillage (ZT) is commonly used by IGP farmers in wheat production, particularly in NW India. In rice-growing areas, ZT makes it easier to sow wheat early. With mechanised planting equipment (e.g. Turbo happy seeder) that can easily manage loose straw remaining in the field after rice combine harvesting and drill seed and fertiliser directly through the residues at the right depth (Sidhu *et al*. 2015). In comparison to CT wheat, Sidhu *et al*. (2015) found that yield performance was superior under ZT with residue retention. When compared to CT wheat, Erenstein and Laxmi (2008) [15] found that ZT boosted wheat yields by 5-7 percent. In comparison to CT wheat, Yadav *et al*. (2005) found that residue integration increased wheat production by 15%. Grain yield increased by 9-11 percent with ZT wheat with rice replanting, according to Sidhu *et al*. (2007) [34]. Kader *et al*. (2017) found that ZT with residue retention resulted in greater wheat yields, possibly because to the cumulative impacts of superior light interception, favourable soil and canopy temperature, and more soil moisture, which resulted in more yield qualities than CT methods. According to Nawaz *et al*. (2017), wheat productivity was considerably greater under zero tillage wheat (ZTW) than CTW in terms of productive tillers, grains per spike, 1000-grain weight, biological yield, grain yield, harvest index, and water productivity. Other smart techniques, such as the site specific nutrient management (SSNM) method, also help to reduce the spatial and temporal variability in soil fertility in smallholder farming systems. Improved management methods offer a strong adaptive capacity to withstand climate adversities in agriculture, according to Jat *et al*. (2016) in South Asia and Latin America. Weather forecasting and early warning systems will aid in reducing the risks of climate change-related losses.

Conclusion

The impact of CSAPs on the productivity of the RW system Improved management approaches, according to Ladha *et al*. (2015), boost yield, reduce water and energy use, and lessen negative impacts on environmental quality in rice-wheat rotation. The total productivity of the rice-wheat cropping system has been reported to enhance when DSR is followed by zero or conventional tillage wheat (Yadav and Yadav, 2012). Rice and subsequent wheat crops yielded much more grain and straw thanks to DSR. Jat *et al*. (2014) [21] conducted a long-term experiment at BISA farm Samastipur, Bihar, to evaluate the performance of CA base technologies in the RWC system. They found that higher grain yields and economic benefits of CA were realised after 2-3 years as the adaptation of CA based practises evolved over time. In the medium term, CA-based systems for rice-wheat rotation in the Eastern IGP of South Asia will be agronomically and economically superior to CT-based systems.

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