ISSN: 2735-0312 (Online)
CODEN: RFAEAW

Reviews In Food And Agriculture (RFNA)

DOI: <http://doi.org/10.26480/rfna.02.2021.76.82>

RESEARCH ARTICLE

ROLE OF CONSERVATION AGRICULTURE IN SUSTAINABILITY OF RICE-WHEAT CROPPING SYSTEM IN NEPAL

Sweta Pandey^{a*}, Swastika Shrestha^b, Ruchita Bhattarai^b, Anu Sharma^a

^aInstitute of Agriculture and Animal Science, Tribhuvan University, Paklihawa

^bAgriculture and Forestry University, Rampur

*Corresponding author email: swetapan456@gmail.com

This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 19 January 2021
Accepted 22 February 2021
Available online 01 June 2021

ABSTRACT

Rice Wheat Cropping system is a major cropping system in Nepal representing one-fourth of the total cultivated land. 83% of the population are dependent on the system for income and employment. However, there are serious threats to sustainability of the Rice Wheat Cropping system in Nepal. The conventional practices are water, labor, and nutrient intensive. Puddling the soil for rice has degraded soil structure in the field and long turn-around period between rice and wheat has delayed wheat planting. Both have contributed to stagnant yield and therefore to low profitability of the Rice Wheat Cropping system. Various literatures related to conservation agriculture, its practices and its role in maintaining sustainable agriculture were studied and enough information were gathered for argument. Conservation agriculture practice mainly focuses on minimal soil disturbance, crop rotation and mulching. Conservation agriculture includes zero tillage, integrated nutrient management, alternate drying and wetting, bed planting and mulching, and crop rotation to diminish the threats to sustainability of Rice Wheat Cropping system. In Nepal, the extension work has been carried out as Climate Smart Agriculture which comes under Conservation Agriculture. However, less research and hesitation of farmers to adopt the technology have created hurdles in extension of conservation agriculture. Conservation Agriculture has proven itself to be the best cultivation practice to enhance productivity of any land without overexploiting the natural resources. Such technology is important to sustain our agriculture in future. Hence, CA is of utmost importance to sustain the livelihood of Nepalese farmers, which is, Rice-Wheat Cropping system of Nepal.

KEYWORDS

Conservation Agriculture, Rice-Wheat, Sustainability, Nepal.

1. INTRODUCTION

The largest agricultural production system worldwide is the Rice-Wheat Cropping system which is practiced on 24 M ha in Asia with four countries Bangladesh, India, Nepal, and Pakistan along the Indo-Gangetic Plains (IGP) and into the mid-hills of Himalayas (Nawaz et al., 2019). According to Ministry of Agriculture and Livestock Development (MoALD), Nepal, rice (*Oryza sativa*) is cultivated in 1,491,744 ha area with the productivity 3.76 Mt/ha whereas wheat (*Triticum aestivum*) occupies around 703,992 ha of land with productivity of 2.85 Mt/ha in the fiscal year 2018/2019. The total paddy cultivation occupies more than 80.0% of total cultivated land (Ministry of Finance, 2019). Rice-Wheat Cropping system is rice based in Nepal with rice alone contributing 20% of GDP and 53% of total cereal production which includes one third of the total calorie intake of Nepalese (Tripathi et al., 2019). The Ministry of Finance (MoF), has documented the contribution of 2.30 % in GDP by wheat in 2014. Food security of Nepal revolves around the Rice-Wheat Cropping system as it represents one fourth of total cultivated land providing food, income, and employment to 83% of the population (Tripathi et al., 2002).

Even after being the principal agricultural production system of the country, Rice-Wheat Cropping system (RWCs) is facing declination of yield

in recent years. Increasing production cost, shortage of water, energy and labor, diminishing farm profits and uncertain whether events are the main challenges faced by the farmers under intensive tillage based conventional production system in Indo Gangetic Plains of South Asia (Jat et al., 2014). Heavy tillage, haphazard use of chemical fertilizers, puddling, not only degrades the soil quality and productivity, but also increases cost of production (Hobbs and Morris, 2011). Though there is a requirement of doubling the crop production in Nepal to fulfill the food demand of the growing population in the next 25 years, the productivity and profitability of the cropping system is low. Therefore, maintaining sustainability in RWCs is a major concern to assure food security.

Conservation agriculture (CA), a holistic approach of farming consists of three core practices: permanent or semi-permanent soil cover maintenance, minimum disturbance of soil through tillage and regular crop rotations which helps to sustain crop yields, revitalize soil, increase input efficiency and the income of farms (FAO). Hence, Conservation Agriculture can be best replaced over conventional practice to meet the future food demands whilst sustaining the Rice-Wheat Cropping system. In many developed countries, Conservation Agriculture has been successfully extended and has shown better results. Until 2008, about 105 million ha land followed no-till agriculture (Derpsch and Friedrich, 2009). While Latin America has seen a 74-fold increase (from 670 ha to 49.6 million ha) of the use of this technology since 1987, the USA has

Quick Response Code

Access this article online

Website:
www.rfna.com.my

DOI:
[10.26480/rfna.02.2021.76.82](http://doi.org/10.26480/rfna.02.2021.76.82)

experienced only 6.5-fold increase in the year 2008.

The CA practice increased carbon biomass and nitrogen content while no tillage practice, particularly, increased C_{mic} and N_{mic} content in various soil properties, experimental duration and climatic conditions (Li et al., 2018). Immobilization and mineralization of soil nutrients, distribution and decomposition of residue of crops, and soil microclimate are influenced by the use of tillage practices and crop residue retention (Li et al., 2018). However, in Nepal, Conservation Agriculture is mostly limited to the research field and very few farmers are inclined towards such practices in their field. This paper aims to evaluate the importance, role, and feasibility of Conservation Agriculture in the sustainability of RWCs in context of Nepal.

2. MATERIAL AND METHODS

All the data were collected from secondary sources. The content of this paper was prepared from the reviews of different research articles and review papers from various publications. Places of Literature were collected from many Journals, Government Institutions, Workshop Papers, and other relevant reports.

3. DISCUSSION

3.1 Rice - Wheat Cropping System in Nepal

Rice-Wheat Cropping system shortly called RWCs has been in Nepal, not just as a food-secured cropping system, but also, as a cultural and social tradition. Rice is not just a grain, but an indicator of social status. In ancient times, rice was considered superior and consumed by well-off families while barley, miller, buckwheat, etc. which were consumed by the majority, were considered as inferior. Hence, the RWCs is rice based in Nepal. On 15th of Ashadh (which coincide with the last week of June) as per Nepalese Calendar, National Rice Day is observed all over Nepal where rice seedlings are transplanted in the puddled field by farmers. Even harvesting period is an occasion of celebration in the field. After harvesting rice, the soil is tilled for wheat. Wheat is grown as a winter crop and sowing is done from early Oct to early Nov in hill while sowing in terai is done within Nov.

The crop residue is either burnt or used as feed to livestock. However, with each passing year, researchers have questioned the sustainability of the cropping system in other South Asian countries including Nepal. The excessive use of chemical fertilizers, not incorporating crop residues in the field and intensive tillage for a prolonged duration has degraded soil structures and nutrients. The expensive imports of foreign labors, stagnant yield, and intensive use of water resources have made the cropping system low profitable. As well as the increasing import of rice and wheat in the country and dependence on hybrid varieties over indigenous varieties of the crops have made Nepal more vulnerable to food insecurity.

3.2 Threats in Sustainability of Rice-Wheat Cropping system

3.2.1 Global warming

A group researcher has projected the increment of Nepal's mean annual temperature by an average of 1.2 °C, 1.7 °C and 3°C by 2030, 2050 and by the end of this century respectively (Adhikari et al., 2017). The climate change is sure to affect productivity of rice and wheat, which are highly critical with temperature and precipitation patterns, to a significant degree. For the last two decades, the growth rate of paddy production has been stagnant at 1.4% per year while the threshold temperature has already crossed. It is likely to decline in Terai where the threshold daytime maximum temperature for rice i.e., 29.9°C has surpassed (Adhikari et al., 2017). In Nepal, while 20°C is the minimum optimum threshold temperature for wheat production, the annual increase of temperature in Nepal is 0.06°C (Bhujel et al., 2014). The rise in temperature, however, might increase the productivity of wheat to certain extent as the annual average maximum temperature at the area of wheat cultivation was 18.3°C in Bhairahawa (Thapa-Parajuli and Devkota, 2016).

In the central part of southern Terai, the average annual rainfall decreased at the rate of 10.21 mm/year between 1984 and 2014 (Dhakal et al., 2016). 65% of cultivation is rainfed, hence there are negative impacts on the Rice-Wheat Cropping system due to the spatial and temporal variation in precipitation pattern (Gahatraj et al., 2018). Water stagnated condition in

rice prevents aerobic decomposition of soil organic matter (SOM). Average maximum CH_4 emission from rice fields was found to be 28 kg/ha/season under rainfed conditions from studies conducted at Nepal Agricultural Research Council (NARC), Khumaltar. As for wheat crop it acts as a sink for CH_4 and the major greenhouse gas is N_2O . This alteration of wetting and drying cycle in RWCs promotes N_2O emission (Lamsal and Khadka, 2019).

3.2.2 Soil health, soil fertility and soil structure

Every cycle of RWCs brings about major physical, chemical, and biological changes in soil throughout the time being. A group researcher reported that puddling develops hardpans at shallow depth leading increment in bulk density, declined hydraulic conductivity, oxygen stress, diminished redox potential and enhanced accumulation of phytotoxins in the root zone in the following wheat crop ultimately decreasing the yield (Ladha et al., 2003). Yield reduction in wheat followed by puddled rice was noted as 8-9% against that of non-puddled direct-seeded rice (DSR) (Zhou et al., 2014). Evapotranspiration is high in medium to large clods which are formed upon tillage after rice harvest and have greater surface exposure (Chenkual and Acharya, 1990). The intensive tillage practice in the RWCs promotes leaching and erosion, hence there is loss of soil organic and inorganic nutrients.

Furthermore, the loss of SOM is accelerated by reduction in biological nitrogen fixation and facilitation in mineralization of SOM during wheat crop season (Lamsal and Khadka, 2019). The heavy use of chemical fertilizers has contributed to the poor OMC ultimately declining the soil fertility in more than 60% of the cultivated land (Khanal et al., 2012). Diversified cropping system accompanied by no till reported highest soil microbial activity and diversity under conservation agriculture (Evans and Miller, 1990; Mcgonigle and Miller, 1990). Soil loses phosphorus due to tillage as it impairs and disrupts soil pore networks along with mycorrhizal hyphae (Evans and Miller, 1990; Mcgonigle and Miller, 1990). For a suitable seedbed to plant wheat, farmers usually plough their field many times which leads to late planting of wheat. This results reduction in yield potential along with other negative effects (Hobbs and Gupta, 2003; Hobbs and Gupta, 2004).

3.2.3 Poor water retention

The country has an estimated renewable groundwater potential of about 12 km³ (WEPA, 2018). The agriculture sector is the largest sector, consuming almost 96% of the available annual renewable water (Gurung et al., 2019). Drought is the major yield limiting factor of semi-arid regions. In Nepal, 0.52-million-hectare areas suffer from drought. Due to conventional agriculture such as tillage operation, burning of crop residue rather than incorporating it to soil practiced in Nepal, soil moisture loss is higher (Lamsal and Khadka, 2019). The Ganga basin (India-Nepal) has the highest anthropogenic groundwater loss rate (~22.56±3.8 km³ per year) which is about 42% of total use (Tiwari et al., 2009). Moreover the per capita water availability of Nepal is projected to be 4820m³ by 2020 which was 21632m³ in 1950 (Bhatt et al., 2016). No mulching system and planting in flat land even more increase losses of the water through the field. The production significantly decreases in water shortage. Therefore, it is an emergency to preserve rain water and increase water use efficiency.

This reveals a clear tendency toward drought over central Nepal in past decades. For the 12-month time scale, 65 % (26 out of 40) stations have increasing trend of drought and out of these 20 have significant trend. both monsoon and winter droughts were recorded in more stations since the late 1990s, thus indicating a spread of drought in large parts of central Nepal (Dahal et al., 2016).

3.2.4 Loss through Residue

In Nepal, crop residue is served as major feed for animals and the leftover residue is burnt in the field. About 300N kg/ha, 300K kg/ha and 30kg/ha P is lost from the Rice-Wheat sequence field with yield of 7 tons/ha rice and 4 tons/ha wheat (Singh, 2003). Although nutritional value of straw of rice and wheat is low, they are used as fodder in many Terai and hilly districts here. Moreover, 40-80 percent of nitrogen is lost in the form of ammonia when wheat residue is burnt (Samra et al., 2003). Nepalese Rice-Wheat Cropping system is at risk of depletion of organic and inorganic components of soil unless residue of corresponding biomass is replenished into soil. For stabilizing the agriculture ecosystem, crop residue plays an important role by providing plant nutrients (Lamsal and Khadka, 2019). The application of crop residue has higher impact than the application of green manure. Combination of incorporated green manure,

crop residue and synthetic fertilizers has 10-20% of higher carbon sequestration (Wassmann et al., 2004). Moreover, the uptake of about 25%, 50% and 75% of N and P, K as well as S are retained by cereal crops when crop residues are incorporated (Singh, 2003).

3.2.5 Pest and Disease

Pest and disease create another sustainability issue in RWCs. A group researcher reported that pesticide consumption in Nepal is increasing by about 10-20% every year (Diwakar et al., 2008). Pesticide consumption in Nepal was only 142 gm/ha in 1995 which rapidly grew to 396 gm/ha in 2014. The entire Rice-Wheat Cropping system is cultivated under a high input environment. This system requires sufficient irrigation, agrochemicals (fertilizers and pesticides), micronutrients and organic inputs. This nutrient-rich environment acts as a catalyst for the growth of phytopathogens and insect-pest (Lamsal and Khadka, 2019). Higher dose of nitrogenous fertilizers aimed for increasing yield also promotes disease and insects in wheat. A group researcher found that the wheat planted in bed and no tillage had less blight incidence than that in conventional (Tripathi et al., 2002).

3.2.6 Labor shortage

Apart from being water, energy and capital intensive, puddling, transplanting, spraying, and harvesting makes RWCs more labor intensive. The results by some researchers revealed the aim of migration among people in mid hills of Nepal are: 1 (Jaquet et al., 2019). Move out of poverty 2. Provide quality education to future generation 3. Ensure food security 4. Enhance family finance. Malaysia, Qatar, Saudi Arabia, and the United Arab Emirates are the major countries where 90% of Nepalese laborers find employment while India attracts very poor laborers from far western hill areas of the country who cannot afford abroad travel (Pant, 2013). In the same report, Pant has stated that the agricultural gross output is reduced by NRs. 18,000 per one labor migration. Hence the fields are left barren or foreign laborers with high wages are employed in RWCs.

3.2.7 Yield Stagnation

In Nepal, the productivity of rice and wheat were below in comparison with other South Asian countries i.e. 3.36 t/ha and 2.59 t/ha respectively though it was increasing at the rate of 1.65% and 2.52% between 1995 to 2014 (Gairhe et al., 2018). The yield trend of rice and wheat is stagnant in recent years. The continuity of conventional farming systems, degrading the soil productivity and climate change is the main reason behind yield stagnation. Moreover, farmers do late sow of wheat since the long duration rice varieties mature lately providing farmers with less turnaround time for seedbed preparation of wheat. The rainfall hits the late planted long duration varieties of wheat during harvesting which affects the production. Hence the sustainability of RWCs is also affected by the incompatibility of rice and wheat varieties (Lamsal and Khadka, 2019).

Figure 1: Trend Analysis of Yield of Rice and Wheat during 2009/10 - 2018/19 in Nepal Source: MOALD (2020)

3.2.8 Poor income

In Nepal, the profitability of RWCs is below its potential and much lower than its neighboring countries of South Asia where RWCs is followed. Lower resource conservation technology resulting in low productivity and expensive inputs such as operating tiller, agrochemical, labor cost resulting in high cost of production lead to the loss or less profit. In terms of crop production and net profit, conservation agriculture is more

beneficial than conventional agriculture (Prasai et al., 2018; Sravanthi et al., 2016). The less income through agriculture is the main reason for Nepal to become economically poor country since majority of Nepalese are from agriculture background. The traditional farming system is the reason behind poor income through agriculture.

3.3 Conservation Agriculture

According to FAO, Conservation Agriculture (CA) is a farming system that can prevent losses of arable land while regenerating degraded lands. A permanent soil cover is maintained, minimum disturbances to soil is done and plant species are diversified. CA is eco-friendly and as it recycles nutrients, causes less damage to soil, requires less water, and increases water use efficiency, emits less carbon as compared to conventional agriculture. A study done by showed that the productivity and net returns from basmati Rice-Wheat Cropping system under CA was higher by 36% and 43% respectively than the conventional system with lower labor utilization per area, lower input cost and less irrigation in respect to ponding time (Jat et al., 2019). Early maturity of crops i.e. 90% in wheat and 100% in rice was also observed by the farmers from the CA practice of the same experiment by (Pokharel et al., 2018). In the same experiment, the quantity of seed used for wheat production dropped from 200kg ha⁻¹ to 100kg ha⁻¹ when farmers adopted Zero Tillage.

3.3.1 Zero tillage or reduced tillage

Zero tillage is one of the primary categories of conservation agriculture. Also known as conservation tillage, here, seeds are directly placed to required depth and spacing using zero till seed cum fertilizer drill or other heavy seeder depending upon presence or absence of crop residue (FAO). This technology not only maintains the soil structure but also increases nutrients in soil, preserves soil microorganism, decreases soil moisture loss ultimately increasing the productivity. In an experiment conducted in Nepal, the productivity of zero tillage and reduced tillage was higher by 780 kg/ha and 454kg/ha respectively and the cost of production for sowing was lower by Rs 1160/ha and Rs 1510/ha respectively as compared with farmers practice (Jat et al., 2019). In zero tillage with residue recycling, the soil organic content was increased by 21% as compared with conventional (Jat et al., 2014). Weed emergence is comparatively low in zero tillage practice. In conventional practice, two- or three-times heavy tillage followed by puddling is done in a rice field which disturbs the soil's physical and chemical properties.

The development of sub-surface compact layer is formed at 14-20 cm due to puddling at depth of 10-12 cm that persists even in post-rice wheat seedbed preparation (Kukul and Aggarwal, 2003). This results in the loss of grain yield of wheat. Therefore, it is urgent to extend the zero-tillage practice to the farmer's field for increasing productivity and maintaining sustainability. In Sunsari, unpuddled transplanted rice followed by zero tillage wheat was found to be beneficial with a B:C ratio of 2.96 and grain yield of 8.11 ton per ha while the B:C ratio was only 2.27 in conventional Rice-Wheat Cropping system (Pokharel et al., 2018). These research results show that zero tillage is not only eco-friendly but also has higher productivity and can be replaced easily over the traditional system of tillage. The grain yield under CA (4766 kg ha⁻¹) was significantly higher than conventional agriculture (4106 kg ha⁻¹) (Marahatta et al., 2018).

3.3.2 Integrated Nutrient Management

The long-term use of single organic manures brings the threats of unsustainable production and the excessive use of only chemical fertilizer deteriorates the soil quality (Pandey et al., 1998). Integrated Nutrient Management ensures sustainability by designing farming systems that improve soil health and food security (Sharma et al., 2019). A group researcher suggested to use FYM to maintain the soil fertility and recommended 10 t/ha FYM + 50 kg N/ha in paddy while for the sustainability of Rice-Wheat Cropping system, 100-30-30 kg N: P₂O₅: K₂O was recommended (Shrestha et al., 2015). Nowadays even after applying NPK, farmers experience a decrease in yield. The application of balanced fertilizer alone doesn't sustain soil fertility in the long run but combining it with FYM boosts up the crop yield and improves physical properties of soil (Kabeerathumma et al., 1993; Lal et al., 1990). A group researcher concluded that potassium as the limiting factor for sustainable yield (Rawal et al., 2017). Soil pH maintenance and soil nutrient availability is highly dependent on soil organic matter so applying FYM and adding potassium fertilizer and crop biomass enhances sustainable yield (Shrestha, 2015).

3.3.3 Alternate Wetting and Drying (AWD)

Alternate Drying and Wetting (AWD) is the continuous cycling of flooding, draining and re-flooding in accordance to crop stage and critical water requirement to maintain optimum water level in all stages of crop life (Lamsal and Khadka, 2019). First the rice field is dried until optimum water is left for crop growth. Tensiometer is used to check the water level in the field. Reflooding is done when the water level is below optimum. Except in flowering, the field is flooded in all the growing stages of crop (Lamsal and Khadka, 2019). The experiment done by on dry season rice in central Terai of Nepal showed no significant difference in yield between treatment plots, although AWD plots received 57% less water requirement than conventional plots (Howell et al., 2015). In a similar experiment observed 27.3% less water consumption with no yield loss compared to conventional (Djaman et al., 2018). Apart from water use efficiency AWD system enhances tillering, root growth and helps cut off CH₄ emission from rice fields by a significant amount. Rhizosphere drying caused by AWD can also alter plant hormone signaling and enhance grain filling rate, particularly in inferior spikelet thereby increasing plant water use efficiency (Zhang et al., 2010, 2012; Tabbal et al., 2002; Davies et al., 2011). A major barrier to the widespread adoption of AWD is that its effects on yield (positive or negative) vary considerably between different soils, climates, cultivars and management practices (Bouman and Tuong, 2001; Price et al., 2013).

3.3.4 Mulching and Bed Planting

In the semi-arid region like Nepal where rainfall intensity is high but short duration, furrow diking technology in bed planting and mulching is important (Lyle and Dixon, 1977). Mulching reduces the weed stress and soil moisture loss and provides nutrients to the soil. The bed planting system is adopted for improved water and nutrients efficiency, lower seed rate, better plant stands, opportunity for weed control prior to planting mechanical weed control between the beds early in the crop cycle, reduced dependence on herbicide, lower hand weeding, less crop logging, and more opportunity for crop diversification (Hobbs and Giri, 1997). A study reported higher production (3524 kg/ha) under bed planting as compared to farmer practice (2996kg/ha) and the total annual grain yield was enhanced by more than 1100kg/ha in the bed planting system with mulching (Tripathi et al., 2002). On bed planting of rice-wheat-mungbean system, increment in the mean annual total grain yield was reported to be more than 600 kg/ha against flat planting (Sah et al., 2011). In the same report, bed mulch helped in the increment of total grain yield was reported to be more than 1100 kg/ha. However, the production cost for land preparation and sowing is higher in bed planting which can be reduced by permanent beds technology. The participatory research conducted in farmers' fields in hilly regions was successful and was able to reduce 20-25 % cost of production over conventional methods of agriculture under permanent bed planting in RWCs (Bhattarai et al., 2004).

3.3.5 Crop Rotation

Variation in cropping pattern in every cropping season changes the rhizosphere affected soil area by replenishing the depleted nutrients. *Bradyrhizobium* sp. and *Herbaspirillum* sp. are found to colonize the rice roots when grown in rotation with the legume, promoting rice growth and availability of plant nutrients especially nitrogen and phosphorus (Zhou et al., 2014). In crop rotation, along with biological nitrogen fixation, legumes improve nutrient availability, soil structure, reduces disease incidence and promotes mycorrhizal colonization (Cupina, 2014; Wani et al., 1995). As high yielding improved variety is preferred, the higher need of nitrogen by high yielding rice cultivar could be met by legume thereby increasing growth and yield (Yadvinder-Singh et al., 2004). Grain legumes in crop rotation can provide two benefits: addition of nutrients to soil and second is additional income and source of vegetable protein (Gathala et al., 2014; Timsina et al., 2006; Yadvinder-Singh et al., 2004). The additional nutrient added by the legumes not only enhances the grain yield but also reduces the cost of production by lowering the use of chemical fertilizer and providing better economic return to farmers without having haphazard results in the environment.

3.4 Feasibility of CA in Nepal

The less availability of labors, absence of quality inputs, site specific nutrient and pest management options and sustainable intensification of cereal based farming can be addressed by CA in Nepal (Pandey et al., 2018). The potential CA technologies in Terai are precision land leveling,

furrow irrigation with raised bed planting system, no tillage, crop residue management, crop diversification, etc. Strip cropping, crop rotation with legumes, intercropping and introducing high yielding varieties are the potential CA technologies in hill (Karki and Shrestha, 2015). The socioeconomic characteristics, land topography and availability of quality inputs determine the adoption of CA practices by the farmers and their numbers (Pokharel et al., 2018). Some tools used in hills are mini power tiller fitted with seed drill, weed mower and chopper, punch and jab planter which has drill for both seed and fertilizer.

In terai, multi crop, trash movers, zero-till ferti-seed driller fitted with inverted-T openers, punch planters, etc. are used in loose residue (Karki and Shrestha, 2015). A group researcher concluded that practices under CA in Rice-Wheat Cropping system as a viable option for Eastern Indo Gangetic Plain (EIGP) of Nepal as it improved the crop productivity to 8.11 t ha⁻¹ as compared to 8.08 t ha⁻¹ in conventional agriculture, reduced the cost of cultivation i.e., NRs.78,395 ha⁻¹ as against NRs.102,727 ha⁻¹ and decreased labor use per hectares i.e., 71 people day⁻¹ ha⁻¹ as against 106 for conventional (Pokharel et al., 2018). While there is decline in labor approvals from 2017/18 to 2018/19 (Jaquet et al., 2019). The shortages of labor in agriculture still exist in the field which can be considered by CA.

3.5 Extension of CA to farmer practice

Demarcation between Conservation Agriculture (CA) and Climate smart Agriculture (CSA) has not been marked. However, the practices under CA have been marked as CSA and Nepal has been more acquainted with sustainability as CSA. A multi-stakeholder approach practice at local level to promote CSA is Climate Smart Village (CSVs) which was developed by ICIMOD with Environment and Agricultural Policy Research, Extension and Development. A group researcher concluded that CSA technology can be scaled out in places with similar conditions like Nawalparasi, Hills and high hills area of Kaski and Lamjung where it was tested and evaluated as pilot projects (Khatrri-Chhetri et al., 2017). DADO Sunsari has supported the spread of CA technologies for wheat through policy and additional farmers' visit to demonstration plots, training programs with dissemination of leaflets and pamphlets advocating CA technologies. It reported a total 250 farmers with 350 ha using ZT in different cereal crops (Pokharel et al., 2018). For rice-based systems in eastern and mid Terai, CSISA has been working to promote CA based technologies (Karki and Shrestha, 2015).

3.6 Challenges

Although the government, NGO and INGO have been working for extension of CA practices to the farmer's field, there are still many barriers for its adaptation by farmers. To mention: 1. To change the mindset of the conventional tillage-based farming that has been working for generations and has cultural values and rural tradition and 2. Lack of farmer's field research in CA which could help farmers gain an experience of CA practice and know about benefits - are two main intellectual barriers for CA to overcome (Karki and Shrestha, 2015). Moreover climatic diversity and different socioeconomic characteristics makes the technology more complex in Nepal as the adaptation is influenced by agroecology, socio-economic factor, agroecology and ascribe of new technology (Cabell and Oelofse, 2012). Further unavailability of machinery equipment makes CA challenging. Even if available, most of the farmers are poor and cannot afford mini-power tiller, seed drill machines, etc. used in CA. Though the government has subsidized the price, these are still out of reach in many regions of Nepal, especially in the hilly regions due to difficult geographical topography and poor information flow.

3.7 Policy and institutional support

The country's policy plays an important role in extension of conservation agriculture and adoption by farmers. The spreading of CA usually takes a longer period without policy and institutional support due to different constraints. The proper policy with its implication is necessary for the rapid extension of CA. However, in some countries the policy is made for CA but also support for the heavy mechanization. Similar is the case in Nepal. The country has made policy for CSA in support of CA on one hand, while, on the other hand, the Prime Minister Agricultural Modernization and Mechanization, though, subsidies the price of mini tillers, it is also supporting heavy mechanization (such as rotavator, combine harvester) in a field which is totally against CA. Hence calculated, proper and fair policy is required for extension of CA.

3.8 Future research work

Conservation agriculture has greater potential and is the best alternative to conventional agriculture in context of poor nutrients cycling, labor and water shortage, low productivity, and profitability along with increasing global warming. CA is gaining more popularity among the farmers as it provides higher economic returns. CA, along with being cost effective and providing higher profitability, it adds to sustainability. To realize its higher benefits and extension in RWCs of Nepal, furthermore research and study are needed on the same topic. Following are some suggestions provided for the same purpose:

- Research and study to find out the suitable CA based technology on different agroecological should be carried out as CA technology varies in different ecologies.
- More emphasis must be given to CA based research in farmers' field along with assurance of compensation to farmers in case of failure which encourage farmers to adopt CA in their field.
- Research to analyze social hesitations of farmers to adopt the CA can bring so solution to table.
- Easy availability, accessibility, and affordability of Agri inputs, operating machines like mini-tiller, seed drill machines, etc. used in CA.
- Training should be provided to farmers on the importance and practices of CA at local level.
- Long term research to analyze the potential of CA practices in hilly regions need immediate attention.
- Research on impact of CA practices in other commercial crops like soyabean, sugarcane, potato, etc. can be carried out.

4. CONCLUSION

Conventional agriculture practiced in Nepal has low productivity with poor resource conservation. Moreover, it requires expensive inputs and labor meanwhile, most Nepalese farmers are poor and the trend of youth migration in foreign countries is high. The main problem in conventional practice is degradation of soil health, quality, and its productivity. These all result in a higher gap between grain yield and potential yield. In this situation, conservation agriculture can be the best alternative for sustainable production in RWCs. Conservation agriculture maintains soil quality, enhances soil nutrients, reduces moisture loss, and provides higher economic return. The researches on CA in other countries and limited parts of Nepal have verified its contribution in yield increment, better water use efficiency, low production cost, better income, and low labor. Despite all the benefits, its adoption is very less in Nepal due to less availability of mini tillers and zero till ferti-seed drill with inverted-T openers among farmers and unwilling to change the trend of conventional tillage due fear of low production. However, this problem can be solved by extending research on the farmer's field and subsidizing the price of machines. Not only the conventional practices but global warming, climate change has also affected agriculture so it is the peak time for adaptation of conservation agriculture. Climatic diversity is the main feature of Nepal, so the authors of this article suggest the future research endeavor to research more on the CA technology that best suits each agroecology of Nepal.

ABBREVIATIONS

CA - Conservation Agriculture
 CSA – Climate Smart Agriculture
 CSISA- Cereal Systems Initiative for South Asia
 DSR - Dry Seeded Rice
 GDP - Gross Domestic Product
 ICIMOD - International Centre for Integrated Mountain Development
 IGP- Indo-Gangetic Plain
 INGO – International Non-Governmental Organization
 MoALD- Ministry of Agriculture and Livestock Development
 MoF - Ministry of Finance
 NARC - National Agricultural Research Council
 NGO - Non-Governmental Organization
 RWCs - Rice-Wheat Cropping System

SOM -Soil Organic Matter
 ZT- Zero Tillage

REFERENCES

- Adhikari, V., Devkota, N., Phuyal, R., 2017. The Impact of Climate Change on Paddy Production in Nepal.
- Bhatt, R., Kukal, S.S., Busari, M.A., Arora, S., Yadav, M., 2016. Sustainability issues on rice–wheat cropping system. In International Soil and Water Conservation Research. International Research and Training Center on Erosion and Sedimentation and China Water and Power Press, Vol. 4, Issue 1, Pp. 64–74. <https://doi.org/10.1016/j.iswcr.2015.12.001>
- Bhattarai, S., Munankarmy, R.C., Shrestha, S., Al, E., 2004. NARC ELIBRARY. Proceedings of the Seventh National Outreach Research Workshop Held at NARC, Pp. 202–210.
- Bhujel, R.B., Jha, R.N., Yadav, B., 2014. An Empirical Analysis of Resource Productivity of Wheat in Eastern Tarai Region of Nepal. Nepal Agriculture Research Journal, 9, Pp. 99–108. <https://doi.org/10.3126/narj.v9i0.11647>
- Bouman, B.A.M., Tuong, T.P., 2001. Field water management to save water and increase its productivity in irrigated lowland rice. Agricultural Water Management, 49 (1), Pp. 11–30. [https://doi.org/10.1016/S0378-3774\(00\)00128-1](https://doi.org/10.1016/S0378-3774(00)00128-1)
- Cabell, J.F., Oelofse, M., 2012. An indicator framework for assessing agroecosystem resilience. The Resilience Alliance, In Ecology and Society, Vol. 17, Issue 1. <https://doi.org/10.5751/ES-04666-170118>
- Chenkual, V., Acharya, C., 1990. Effect of rice-wheat and maize-wheat rotations on soil physical properties including soil water behaviour in an acidic Alfisol. Journal of the Indian Society of Soil Science, 38 (4), Pp. 574–582.
- Cupina, B., 2014. Cover Crops for Improving Crop and Soil Management. Advances in Plants & Agriculture Research, 1 (2). <https://doi.org/10.15406/apar.2014.01.00009>
- Dahal, P., Shrestha, N.S., Shrestha, M.L., Krakauer, N.Y., Panthi, J., Pradhanang, S.M., Jha, A., Lakhankar, T., 2016. Drought risk assessment in central Nepal: temporal and spatial analysis. Natural Hazards, 80 (3), Pp. 1913–1932. <https://doi.org/10.1007/s11069-015-2055-5>
- Davies, W.J., Zhang, J., Yang, J., Dodd, I.C., 2011. Novel crop science to improve yield and resource use efficiency in water-limited agriculture. Journal of Agricultural Science, 149 (S1), Pp. 123–131. <https://doi.org/10.1017/S0021859610001115>
- Derpsch, R., and Friedrich, T., 2009. Development and Current Status of No-till Adoption in the World. 18th Triennial Conference of the International Soil Tillage Research Organisation (ISTRO), proceedings on CD.
- Dhakal, S., Sedhain, G., Dhakal, S., 2016. Climate Change Impact and Adaptation Practices in Agriculture: A Case Study of Rautahat District, Nepal. Climate, 4 (4), Pp. 63. <https://doi.org/10.3390/cli4040063>
- Diwakar, J., Prasai, T., Pant, S.R., Jayana, B.L., 2008. Study on Major Pesticides and Fertilizers used in Nepal. Scientific World, 6 (6), Pp. 76–80. <https://doi.org/10.3126/sw.v6i6.2638>
- Djaman, K., Mel, V., Diop, L., Sow, A., El-Namaky, R., Manneh, B., Saito, K., Futakuchi, K., and Irmak, S., 2018. Effects of Alternate Wetting and Drying Irrigation Regime and Nitrogen Fertilizer on Yield and Nitrogen Use Efficiency of Irrigated Rice in the Sahel. Water, 10 (6), Pp. 711. <https://doi.org/10.3390/w10060711>
- Evans, D.G., Miller, M.H., 1990. The role of the external mycelial network in the effect of soil disturbance upon vesicular—arbuscular mycorrhizal colonization of maize. New Phytologist, 114 (1), Pp. 65–71. <https://doi.org/10.1111/j.1469-8137.1990.tb00374.x>
- FAO. Conservation Agriculture. Retrieved from Food and Agriculture Organization of the United Nations: <http://www.fao.org/conservation-agriculture/en/>

- FAO. Retrieved from Food and Agriculture Organization of United Nations: <http://www.fao.org/3/T1696E/t1696e09.htm>
- Gahatraj, S., Jha, R.K., Singh, O.P., 2018. Impacts of climate change on rice production and strategies for adaptation in Chitwan, Nepal. *Journal of Agriculture and Natural Resources*, 1 (1), Pp. 114–121. <https://doi.org/10.3126/janr.v1i1.22226>
- Gairhe, S., Shrestha, H.K., Timsina, K., 2018. Dynamics of Major Cereals Productivity in Nepal. *Journal of Nepal Agricultural Research Council*, 4, Pp. 60–71. <https://doi.org/10.3126/jnarc.v4i1.19691>
- Gathala, M.K., Kumar, V., Sharma, P.C., Saharawat, Y.S., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphreys, E., Sharma, D.K., Sharma, S., Ladha, J.K., 2014. Reprint of “Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the Northwestern Indo-Gangetic Plains of India.” *Agriculture, Ecosystems and Environment*, 187, Pp. 33–46. <https://doi.org/10.1016/j.agee.2013.12.011>
- Gurung, A., Adhikari, S., Chauhan, R., Thakuri, S., Nakarmi, S., Ghale, S., Dongol, B.S., and Rijal, D., 2019. Water crises in a water-rich country: Case studies from rural watersheds of Nepal’s mid-hills. *Water Policy*, 21 (4), Pp. 826–847. <https://doi.org/10.2166/wp.2019.245>
- Hobbs, P., Gupta, R., 2004. Problems and Challenges of No-Till Farming for the Rice-Wheat Systems of the Indo-Gangetic Plains in South Asia. Figure 1, Pp. 101–120. <https://doi.org/10.1201/9780203026472.ch6>
- Hobbs, P., Morris, M., 2011. Meeting South Asia’s Future Food Requirements from Rice-Wheat Cropping Systems: Priority Issues facing Researchers in the Post-Green Revolution Era Meeting South Asia’s Future Food Requirements from Rice-Wheat Cropping Systems: Researchers in the Po. In *Natural Resource Group*, pp. 1–46.
- Hobbs, P.R., Giri, G.S., 1997. Reduced and zero-tillage options for establishment of wheat after rice in South Asia, Pp. 455–465. https://doi.org/10.1007/978-94-011-4896-2_60
- Hobbs, Peter R., Gupta, R.K., 2003. Resource-Conserving Technologies for Wheat in the Rice-Wheat System, Pp. 149–171. <https://doi.org/10.2134/asaspecpub65.c7>
- Howell, K.R., Shrestha, P., Dodd, I.C., 2015. Alternate wetting and drying irrigation-maintained rice yields despite half the irrigation volume, but is currently unlikely to be adopted by smallholder lowland rice farmers in Nepal. *Food and Energy Security*, 4 (2), Pp. 144–157. <https://doi.org/10.1002/fes3.58>
- Jaquet, S., Kohler, T., Schwilch, G., 2019. Labour migration in the middle hills of Nepal: Consequences on land management strategies. *Sustainability (Switzerland)*, 11 (5). <https://doi.org/10.3390/su11051349>
- Jat, H.S., Kumar, P., Sutaliya, J.M., Kumar, S., Choudhary, M., Singh, Y., Jat, M.L., 2019. Conservation agriculture based sustainable intensification of basmati rice-wheat system in North-West India. *Archives of Agronomy and Soil Science*, 65 (10), Pp. 1370–1386. <https://doi.org/10.1080/03650340.2019.1566708>
- Jat, R.K., Sapkota, T.B., Singh, R.G., Jat, M.L., Kumar, M., Gupta, R.K., 2014. Seven years of conservation agriculture in a rice-wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Research*, 164 (1), Pp. 199–210. <https://doi.org/10.1016/j.fcr.2014.04.015>
- Kabeerathumma, S., Mohankumar, C., Nair, G., Nair, P., 1993. Effect of continuous cropping of cassava with organics and inorganics on the secondary and micronutrient elements status of an ultisol. *Journal of the Indian Society of Soil Science*, 41 (4), Pp. 710–713.
- Karki, T.B., Shrestha, J., 2015. Should we go for conservation agriculture in Nepal? *International Journal of Global Science Research*, 2 (4), Pp. 271–276. <https://doi.org/10.13140/RG.2.1.1459.8488>
- Khanal, N.P., Maharjan, K.L., Dangol, D.R., 2012. Soil Conservation Practices for Sustainability of Rice-wheat System in Nepal: A Review. *Journal of International Development and Cooperation*, 18 (4), Pp. 11–20. <https://doi.org/10.15027/33186>
- Khatri-Chhetri, A., Poudel, B., Shirsath, P., 2017. Assessment of Climate-Smart Agriculture (CSA) Options in Nepal. *LIBIRD and CCAFS*, Kaski, Nepal.
- Kukul, S.S., Aggarwal, G.C., 2003. Puddling depth and intensity effects in rice-wheat system on a sandy loam soil. I. Development of subsurface compaction. *Soil and Tillage Research*, 72 (1), Pp. 1–8. [https://doi.org/10.1016/S0167-1987\(03\)00093-X](https://doi.org/10.1016/S0167-1987(03)00093-X)
- Ladha, J.K., Sharma, P.K., Bhushan, L., Hill, J.E., Duxbury, J.M., Gupta, R.K., Buresh, R.J., 2003. Soil Physical Effects of Puddling in Rice-Wheat Cropping Systems, Pp. 97–113. <https://doi.org/10.2134/asaspecpub65.c5>
- Lal, S., Mathur, B.S., Sinha, K., 1990. Effect of long-term fertilization, manuring and liming of an alfisol on maize, wheat and soil properties-III. *Journal of the Indian Society of Soil Science*, 38 (1), Pp. 21–26.
- Lamsal, S., Khadka, R., 2019. Rice wheat cropping system in Nepal: Issues concerning sustainability. *International Journal of Environment, Agriculture and Biotechnology*, 4 (6), Pp. 1913–1922. <https://doi.org/10.22161/ijeab.46.42>
- Li, Y., Chang, S.X., Tian, L., Zhang, Q., 2018. Conservation agriculture practices increase soil microbial biomass carbon and nitrogen in agricultural soils: A global meta-analysis. *Soil Biology and Biochemistry*, 121(October 2017), Pp. 50–58. <https://doi.org/10.1016/j.soilbio.2018.02.024>
- Lyle, W.M., Dixon, D.R., 1977. Basin Tillage for Rainfall Retention. *Transactions of the American Society of Agricultural Engineers*, 20 (6), Pp. 1013–1017. <https://doi.org/10.13031/2013.35693>
- Marahatta, S., Acharya, R., Joshi, P.P., 2018. Simulation of Growth and Yield of Rice and Wheat Varieties Under Varied Agronomic Management and Changing Climatic Scenario Under Subtropical Condition of Nepal. *Journal of Agriculture and Forestry University*, 2, Pp. 141–156.
- Mcgonigle, T.P., Miller, M.H., 1990. Mycorrhizae, Phosphorus Absorption, and Yield of Maize in Response to Tillage, Pp. 1856–1861.
- Ministry of Finance. 2019. Economic Survey 2018/19. Government of Nepal Ministry of Finance Kathmandu, Pp. 1–340. <https://africacheck.org/wp-content/uploads/2019/03/Economic-Survey-2018.pdf>
- MOALD. 2020. Statistical Information in Nepalese Agriculture. Ministry of Agriculture and Livestock, 290. <https://nepalindata.com/resource/statistical-information-nepalese-agriculture-207374-201617/>
- Nawaz, A., Farooq, M., Nadeem, F., Siddique, K.H.M., Lal, R., 2019. Rice-wheat cropping systems in South Asia: issues, options and opportunities. *Crop and Pasture Science*, 70 (5), Pp. 395–427. <https://doi.org/10.1071/CP18383>
- Pandey, P.R., Pandey, S.P., Khadka, Y., 1998. Long-Term Effect of Organic and Inorganic Fertilizer on Rice-Wheat System in Rainfed Low Land Condition of Khumaltar. *First National Long Term Soil Fertility Evaluation Workshop Organized by Soil Science Division/NARC*, Pp. 116–134.
- Pandey, S., Bhatta, N.P., Paudel, P., Pariyar, R., Maskey, K.H., Khadka, J., Thapa, T.B., Rijal, B., Panday, D., 2018. Improving fertilizer recommendations for Nepalese farmers with the help of soil-testing mobile van. *Journal of Crop Improvement*, 32 (1), Pp. 19–32. <https://doi.org/10.1080/15427528.2017.1387837>
- Pant, K.P., 2013. Effects of Labour Migration on Poverty and Agricultural Growth In Nepal, Pp. 87–101.
- Pokharel, D., Jha, R.K., Tiwari, T.P., Gathala, M.K., Shrestha, H.K., Panday, D., 2018. Is conservation agriculture a potential option for cereal-based sustainable farming system in the Eastern Indo-Gangetic Plains of Nepal? *Cogent Food & Agriculture*, 4 (1). <https://doi.org/10.1080/23311932.2018.1557582>

- Prasai, H.K., Sah, S.K., Gautam, A.K., Regmi, A.P., 2018. Effects of conservation agriculture on crop and system productivity and profitability under maize based system in far western Nepal. *Journal of Bioscience and Agriculture Research*, 18 (2), Pp. 1549–1568. <https://doi.org/10.18801/jbar.180218.190>
- Price, A.H., Norton, G.J., Salt, D.E., Ebenhoeh, O., Meharg, A.A., Meharg, C., Islam, M.R., Sarma, R.N., Dasgupta, T., Ismail, A.M., McNally, K.L., Zhang, H., Dodd, I.C., Davies, W. J., 2013. Alternate wetting and drying irrigation for rice in Bangladesh: Is it sustainable and has plant breeding something to offer? In *Food and Energy Security*, Vol. 2, Issue 2, pp. 120–129.
- Rawal, N., Ghimire, R., Chalise, D., 2017. Crop Yield and Soil Fertility Status of Long-Term Rice-Rice-Wheat Cropping Systems. *International Journal of Applied Sciences and Biotechnology*, 5 (1), Pp. 42–50. <https://doi.org/10.3126/ijasbt.v5i1.17001>
- Sah, G., Karm, M.K.L., Chaudhary, D., 2011. Performance of Permanent Bed Planting under Rice-Wheat-Mungbean Cropping System. *Proceedings of 28th National Wheat Crops Workshop*, Pp. 245–253.
- Samra, J.S., Singh, B., Kumar, K., 2003. In the Rice-Wheat System of the Indo-Gangetic Plain. In *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts*, pp. 173–195.
- Sharma, S., Paddhushan, R., Kumar, U., 2019. Integrated nutrient management in Rice-Wheat cropping system: An evidence on Sustainability in the Indian subcontinent through Meta-Analysis. *Agronomy*, 9 (2). <https://doi.org/10.3390/agronomy9020071>
- Shrestha, G., 2015. Long term soil fertility trial in rice - wheat system in regional agricultural research station, Khajura, Banke: results of soil analysis data from 1998 to 2006 and 2014. In *Proceedings of the Second National Soil Fertility Workshop*, Pp. 24–25.
- Shrestha, G., Shrestha, S., Sah, M.P., El, A., 2015. Long-term Soil Fertility Experiment Under Rice-Wheat Cropping System in Regional Agriculture Research Station, Parwanipur, Bara, Nepal. *Proceedings of the Second National Soil Fertility Research Workshop*, September.
- Singh, Y., 2003. Crop Residue Management in Rice-Wheat System. In *Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia* (pp. 1–320). Rice-Wheat Consortium for the Indo-Gangetic Plains International Maize and Wheat Improvement Center (RWC-CIMMYT).
- Sravanthi, S., Ramana, A.V., Ramana, M.K.V., 2016. Growth, yield and economics of zero till maize as influenced by nutrient management practices in north coastal zone of Andhra Pradesh. *Research on Crops*, 17 (3), Pp. 458–461. <https://doi.org/10.5958/2348-7542.2016.00075.9>
- Tabbal, D.F., Bouman, B.A.M., Bhuiyan, S.I., Sibayan, E.B., Sattar, M.A., 2002. On-farm strategies for reducing water input in irrigated rice; case studies in the Philippines. *Agricultural Water Management*, 56 (2), Pp. 93–112. [https://doi.org/10.1016/S0378-3774\(02\)00007-0](https://doi.org/10.1016/S0378-3774(02)00007-0)
- Thapa-Parajuli, R., Devkota, N., 2016. Impact of Climate Change on Wheat Production in Nepal. *Asian Journal of Agricultural Extension, Economics & Sociology*, 9 (2), Pp. 1–14. <https://doi.org/10.9734/ajaees/2016/22555>
- Timsina, J., Quayyum, M.A., Connor, D.J., Saleque, M., Haq, F., Panaullah, G., Jahan, M.A.H. S., Begum, R.A., 2006. Effect of Fertilizer and Mungbean Residue Management on Total Productivity, Soil Fertility and N-use Efficiency of Intensified Rice-wheat Systems. *International Journal of Agricultural Research*, 1 (1), Pp. 41–52. <https://doi.org/10.3923/ijar.2006.41.52>
- Tiwari, V.M., Wahr, J., Swenson, S., 2009. Dwindling groundwater resources in northern India, from satellite gravity observations. *Geophysical Research Letters*, 36 (18). <https://doi.org/10.1029/2009GL039401>
- Tripathi, B.P., Bhandari, H.N., Ladha, J.K., 2019. Rice Strategy for Nepal. *Acta Scientific Agriculture*, 3 (2), Pp. 171–180.
- Tripathi, J., Bhandari, D., Justice, S., Al, E., 2002. RS2721_Doc17.pdf. *Proceedings of Wheat Research Papers Presented at 25th National Winter Crops Research Workshop Held at NARC*, Pp. 157–165.
- Wani, S.P., Rupela, O.P., Lee, K.K., 1995. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. In *Plant and Soil* (Vol. 174, Issues 1–2, Pp. 29–49). Kluwer Academic Publishers. <https://doi.org/10.1007/BF00032240>
- Wassmann, R., Neue, H.U., Ladha, J.K., Aulakh, M.S., 2004. Mitigating greenhouse gas emissions from rice-wheat cropping systems in Asia. *Environment, Development and Sustainability*, 6 (1–2), Pp. 65–90. <https://doi.org/10.1023/B:ENVI.0000003630.54494.a7>
- Yadvinder, S., Bijay-Singh, Ladha, J. K., Khind, C.S., Gupta, R. K., Meelu, O.P., Pasuquin, E., 2004. Long-Term Effects of Organic Inputs on Yield and Soil Fertility in the Rice-Wheat Rotation. *Soil Science Society of America Journal*, 68 (3), Pp. 845–853. <https://doi.org/10.2136/sssaj2004.8450>
- Zhang, H., Chen, T., Wang, Z., Yang, J., Zhang, J., 2010. Involvement of cytokinins in the grain filling of rice under alternate wetting and drying irrigation. *Journal of Experimental Botany*, 61 (13), Pp. 3719–3733. <https://doi.org/10.1093/jxb/erq198>
- Zhang, H., Li, H., Yuan, L., Wang, Z., Yang, J., Zhang, J., 2012. Post-anthesis alternate wetting and moderate soil drying enhances activities of key enzymes in sucrose-to-starch conversion in inferior spikelets of rice. *Journal of Experimental Botany*, 63 (1), Pp. 215–227. <https://doi.org/10.1093/jxb/err263>
- Zhou, W., Lv, T.F., Chen, Y., Westby, A.P., Ren, W.J., 2014. Soil physicochemical and biological properties of paddy-upland rotation: A review. In *Scientific World Journal*, Pp. 856352–856352. Hindawi Publishing Corporation. <https://doi.org/10.1155/2014/856352>