The rice-wheat cropping system: drawbacks and remedial options in Indian perspectives

S.K. Verma[1], S.B. Singh[2], S.K. Rajpoot[1], Chandra Bhushan[1], D.K. Yadav[1], Vijay Pratap[3] and P.K. Jaishwal[7]

[1]Department of Agronomy, Institute of Agricultural Sciences, BHU, Varanasi-221 005, U.P., INDIA
[2]Department of Agronomy, College of Agriculture, Banda University of Agriculture and Technology, Banda-210 001, U.P., INDIA
[3]Department of Agronomy, RBS, Collage Bichpuri-283 105, Agra, U.P., INDIA
[4]Department of Agronomy, Birsa Agriculture University, Kanke-834 006, Ranchi, Jharkhand, INDIA

Email: suniliari@gmail.com

Rice-wheat cropping system (RWCS) the pre-dominant cropping system in Indo-Gangetic plains (IGP), played a prominent role in fulfilling the food grain demand of the increasing population. In northern Indian plains, the continued adoption of an exhaustive rice-wheat cropping system has resulted in severe deterioration of natural resources, declining factor productivity, multiple nutrient deficiencies, labour scarcity, and also alleviating the cost of production, poses a serious threat to the environment and sustainable crop production. These problems are the major drivers to search for alternative technologies such as varietal development, soil, water, and nutrient management and adoption of resource conservation technologies (laser land levelling, DSR, aerobic rice, systems of rice/wheat intensification, zero/minimum tillage based crop establishment methods) in RWCS are the key interventions to address these challenges. Moreover, conservation agriculture, mechanized transplanting in zero-till / unpuddled fields, and need-based application of water, fertilizer, and pesticides might be a successful approach for a sustainable rice-wheat production system in the current scenario. This article mainly focuses on the drawbacks of the RWCS that arise due to the continuous adoption of this cropping system vis-a-vis alternate sustainable management options for achieving higher productivity and sustainability in northwest India.

Introduction

The rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) cropping system (RWCS) plays a vital role in global food security as it provides staple food to the millions of world's population. This cropping system is extensively followed by most of the technologically advanced nations in the world. In Asia, more than 85% of the RWCS practiced in South Asia is distributed in the Indo-Gangetic Plains, covering nearly 13.5 m ha of area. India alone covers approximately 76% of IGP, spreading over the states of Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal. Being staple food crops in the country, rice and wheat played a key role in minimizing the gap between food grain demand and production. In India, rice occupies an area of nearly 43.8 mha, with a total production of 177.6 mt and productivity of 4,057 kg / ha, whereas, wheat has 29.3 mha area, 103.6 mt production, and 3,533 kg / ha productivity. In recent years, the country witnessed surplus food grain production through an integrated crop management approach and better mechanization. More than 70% of the Indian population consumes rice, and the rest of the population consumes rice along with wheat or other grains.

North Indian plains occupy a large area under RWCS. However, in recent years sustainability of this system in the region has been adversely affected as the yield of both rice and wheat are either stagnated or decreased due to deterioration of soil health, environmental pollution / degradation, decrement in factor productivity, or input-use efficiency, declining ground water table, soil organic matter and nutrient availability; increased soil salinization, incidence of pests and diseases, increase in cost of production and reduction in profit margins. The possibilities of expanding the area under RWCS shortly are limited. Therefore, it needs extra rice and wheat production per unit area to meet the needs of our increasing population. The major challenges are to achieve crop yields with less water, labour, and chemicals, thereby ensuring long term sustainability in the production system. To sustain present food self-sufficiency and to meet future food requirements, India has to increase its rice and wheat productivity by 3 % per annum.

In Asia, Rice is commonly grown by transplanting seedlings into puddled soil. Puddling benefits rice in several ways but, repeated puddling adversely affects soil's physical properties. Moreover, puddling and transplanting require large amounts of water and labor, both of which are becoming increasingly scarce and expensive, making rice production less profitable. Declining crop factor productivity and deteriorating resource base in the rice-wheat system have led to the promotion of conservation tillage based agriculture. Conservation tillage involves zero or minimal tillage for row seeding using a drill / planter. Zero or reduced tillage has had a significant positive impact on the environment, crop productivity, profitability, resource-use efficiency, and farmer’s livelihood, especially in those areas where the rice harvest is normally delayed. Unlike wheat, rice continues to be widely grown under conventional intensive tillage (puddling) and transplanting, which is not only resource use inefficient and energy intensive but also delays the planting of wheat. These factors demand a major shift from puddled-transplanted rice production to direct seeding of rice (DSR) in irrigated areas. According to researchers, low wages and adequate availability of water favor transplanting, whereas high wages and low water availability favor the DSR.

In India, huge amounts of crop residues are produced annually. These residues are used as animal feed, for thatching of homes, and as a source of domestic and industrial fuel. A large portion of unused crop residues are burnt in the fields primarily to clear the left over straw and stubbles after the harvest. Non availability of labour, the high cost of residue removal from the field, and the increasing use of combines in harvesting the crops are the main reasons behind the burning of crop residues in the fields. Burning of crop residues causes environmental pollution, it is hazardous to human health, produces greenhouse gases causing global warming, and results in loss of plant nutrients like NPK and S. Therefore, appropriate management of crop residues assumes a great significance. Recently some microbial consortia and Conservation Agriculture (CA) based crop management technologies were developed which are more resource efficient than conventional practices.

Increasing incomes by reducing crop losses due to various pests and improving productivity and input use efficiency are some of the major recommendations for enhancing income. Weeds are one of the foremost barriers accountable for lower crop yield across all continents, including India. It was estimated that on average the weed control costs around INR 6000 per ha in rainy season crops and around INR 4000 per ha for winter crops, which accounts for around 33% and 22% of the total cost of cultivation, respectively. Thus, efficient weed management can help in increasing the farmers’ income by reducing the losses caused by weeds, decreasing the cost of production, and increasing productivity through efficient utilization of growth resources. Weeds are the main constraint in rice reducing 15 to 90% of yield and 40-68% in wheat if not managed timely. The following are major drawbacks of RWCS (Fig. 1):

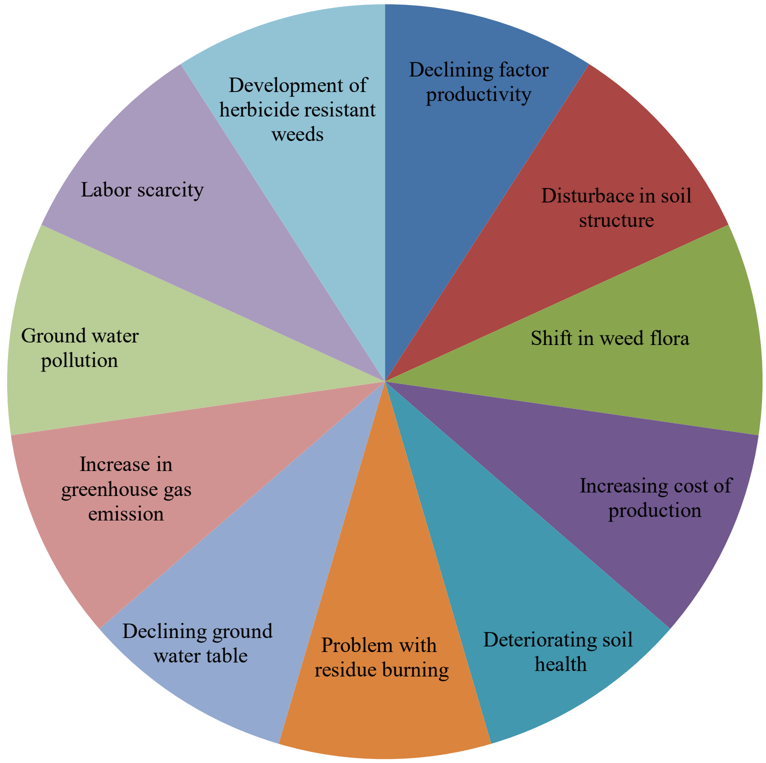

Fig. 1. Drawback of rice-wheat cropping system

Degrading soil structure

Rice is transplanted through tillage under wet conditions (puddling) to reduce percolation losses, facilitate transplanting, and suppress weeds. However, its negative effects through the structural degradation of upland crops are of concern. Apart from extensive labour requirements and repeated puddling operations have led to sub surface compaction, which has been detrimental to the wheat crop. The compactness formed due to repeated puddling restricts the root growth of wheat in addition to creating aeration stress. Thus, the puddled transplanted system of rice is costly and leads to soil structural deterioration. The wheat establishment in RWCS needs multiple tillage operations for their sowing which results in the exposure of the organic matter to the air which ultimately leads to the oxidation of organic matter. These practices in RWCS ultimately lead to the overall structural degradation of the soil. It would be beneficial for soil health if we have to replace the puddled transplanted cultivation of rice with zero-till-based mechanized transplanting, direct seeded rice under unpuddled conditions. The adoption of conservation agriculture-based practices like direct seeding on flat or permanent beds and diversified cropping systems with alternate wetting and drying irrigation methods could be effective in improving the soil structure.

Groundwater pollution

Excessive use of fertilizers and pesticides in RWCS pollutes the underground water. Application of this polluted water for crop production and the dairy sector leads to the emergence of several severe diseases in animals and decreased grain quality which ultimately affects human health. Excessive use of N fertilizers resulting leaching of nitrates leads to the pollution of ground water appears to be a serious concern. The situation is worse in coarse-textured soils where the use of N fertilizer is still higher and the excessive irrigations as generally recommended which is 25% higher than the loam soil. Increasing groundwater pollution is the major issue, and must be attended to. This is true also for the South Western districts of the Punjab, as the underground water is unfit for drinking or even for irrigation. Further, this caused health disorders as more cancer cases were reported from this pocket to such an extent that a "CANCER TRAIN" was running to Rajasthan to treat the cancer patients.

The excess and untimely use of N fertilizer is associated with nitrate leaching, which pollutes the groundwater in RWCS. It is very difficult to stop the nitrogen leaching completely, better management practices by adopting the proper irrigation and fertilizer scheduling based on soil tests can minimize the leaching losses and improve the profitability of the RWCS. Social awareness in farming communities helps in the reduction of groundwater pollution. Grow insect-pest / diseases resistant cultivars that restrict the use of pesticides ultimately help in the reduction of groundwater pollution.

Shift in weed flora

Weed shift is the change and adjustment in the composition or relative frequencies of weeds in a weed population or weed community in response to man-made, natural, and or environmental changes in an agricultural system. Weed shifts occur when weed management practices do not control an entire weed population. Some susceptible weeds are managed by weed control practices, but tolerant or resistant weeds are not controlled. Those species that are not controlled can grow, reproduce, and increase their community; resulting in a weed shift. Due to the intensive cultivation of rice-wheat crops in a sequence, crops are adversely affected by the diverse weed flora due to heavy competition for growth resources. In the rice and wheat growing areas 2, 4-D is used for the control of broadleaf weeds. In both crops, broadleaf species were controlled successfully whereas; annual grass species were predominant in that particular area. Cultivation changes also influenced shifts in weed populations. Direct seeding of rice has been replaced by transplanting in Asia, and the annual grassy weeds like *Echinochloa colona and E. crusggali* have become dominant by replacing the population of previously dominant upland weeds like *Monochoria vaginalis* and *Ludwigia hyssopifoli.*

Declining factor productivity

The factor productivity is the ratio of the total output value to the total input cost used to assess production efficiency over a short period. The declining trend of total factor productivity in agriculture is a severe threat to sustainable farming and food security. In recent years, a significant portion of the cultivable land faced stagnation or negative growth in total factor productivity. The decline in factor productivity from a farmer's point of view is considered a serious issue in the sustainable cropping system. With continued adoption of RWCS, crop yield is adversely affected by multiple factors and yields are somehow of both crops decrease or stagnate. It has been observed that input use efficiency decreased with increased cost of cultivation which further increased the risk of probability.

Long term practice of RWCS in IGP over the years, injudicious and unbalanced application of fertilizers, inappropriate timing of fertilizer application, and low soil organic matter are other factors responsible for declining crop response to applied fertilizers. The current trend of decline in crop response to applied fertilizers would create more difficulties for any further improvement in crop productivity. Therefore, soil and water management, integration of green or brown manuring, growing of dual purpose pulses, and addition of organic manure along with inorganic fertilizers are required to reverse the trend and improve the crop response in the long run.

Labour scarcity

RWCS is a water, energy, capital, and mostly labour-intensive system as transplanting, weeding; spraying and harvesting of crops require more labour. Labour shortages are an emerging issue in the prevailing RWCS due to the same time of transplanting (June-July) and they also engage in other crops they are established in the same period. The labour scarcity has been increasing over the last few years due to assured working days offered under Mahatma Gandhi National Rural Employment Guarantee Act. (MANREGA) scheme of Govt. of India and thus the flow of labour to other regions is decreased to a remarkable extent. It has also been observed that manual transplanting of rice results in fewer seedlings per unit area compared to the recommended level of 30–40 plants per m^2. Mechanical transplanting of rice is being adopted, which may tackle the issues of labour scarcity, higher labour cost, and delay in rice transplantation.

Increase greenhouse gas emission

RWCS produces huge crop residues which are generally burnt *in-situ* for the timely sowing of wheat crops. Burning of crop residues generates huge amounts of greenhouse gases (GHG) aerosols and other hydrocarbons in the atmosphere affecting the atmospheric composition. This change might have a direct or indirect effect on the radiation balance. These gases may lead to a regional increase in the levels of aerosols, acid deposition, and depletion of the ozone layer which protects us from harmful sun rays. Repeated tillage operation during puddling consumes more fuel and thereby increases CO_2 levels and standing water under puddled conditions increases CH_4 emission. Also, pumping out the water for irrigation requires diesel engines or tractors which are responsible for higher CO_2 emissions. Puddled transplanted rice in RWCS and residue burning are substantial anthropogenic sources of CO_2 and CH_4 contributing the 20.9% of total GHG emissions. Changing cultivation practices from puddled transplanting to non-puddled transplanting using zero-till, mechanized transplanting, zero tillage + residue retention, DSR, SRI and aerobic rice reduces greenhouse gas emissions along with the benefit of carbon storage in the soil. However, it requires more research efforts to address weed control, soil-borne pathogens, and grain quality challenges. A shift from cereal–cereal production system to leguminous-cereal cultivation or replacing rice–wheat with a maize–wheat cropping system periodically under zero-till or CA practice could be beneficial for sustainable crop production. The integrated approach of adopting low-duration and lesser water-requiring varieties, water management, residue management, and RCTs in RWCS can mitigate environmental pollution.

Multiple nutrient deficiencies

Before the mid-sixties, only macro-nutrient supply was provided through the use of commercially available fertilizers however with time, the soil health started to decline and micro-nutrient deficiencies were also reported in the RWCS. This system not only extracted important nutrients (N, P, K, and S) from the soil but also generated a nutrient imbalance in the soil leading to soil degradation. Zinc deficiency has become common in the IGP and it is now the third most limiting nutrient after nitrogen and phosphorus, especially in soils with high pH and those irrigated with low quality water. As 80-85% of the K absorbed by rice and wheat crops remains in the straw, removing/ burning all of the straw from crop field's results in K deficiency. The burning of crop residue is not only associated with air pollution but also with the loss of precious nutrients retained in the crop residue. During crop residue burning, almost 100% carbon, > 90%

nitrogen, 20–25% phosphorus, potassium and about 60% sulphur are lost in the form of various gases and particulate matter.

Global warming

Global warming is an emerging serious threat to the agriculture sector and it poses a variety of challenges, including an increase in temperature, CO_2, N_2O, and rainfall, which affect the growth and development of plants directly and indirectly through irrigation, weed growth, and insect and disease outbreaks. The mortality of useful soil fauna and microorganisms is caused by the burning of leftover residue, which also contributes to poor air quality, human respiratory diseases, and the death of beneficial microorganisms in soil due to intense heat generation. Hence different techniques must be developed and adopted at a large scale in the region which could ultimately reduce the production of the GHGs such as direct drilling of the wheat seeds in standing rice stubbles using "Happy Seeder" and direct seeding of rice.

Increase the cost of production

RWCS is the most preferred cropping system in northwest India because of its advantages like assured price and good crop yield. Conventional transplanted rice highly depends on labour availability in almost all rice-growing areas. In the north-western part of the country particularly Punjab, Haryana, Uttrakhand, Rajasthan, and western parts of Uttar radish are largely dependent on migrant labour for rice cultivation. Due to the engagement of labours in MNREGA, labour costs have increased many times for transplanting of rice and it is rising every year. In addition, the gap between the cost of production and the minimum support prices of rice and wheat crops has increased over the years, adversely affecting the overall profitability.

Declining groundwater table

India is the prime groundwater user on the planet; more than a quarter of the total global water use is being used here. The decline in the groundwater table was reported by many researchers wherever RWCS is adopted by the farmer for a longer period, which ultimately affects crop water productivity. Northwest parts of India particularly Panjab and Haryana which is a non-traditional rice belt are producing rice through the mining of ground water is the major cause of declining of the water table very fat. The puddled transplanted rice is a high water demanding system over DSR. Further, there is a large amount of loss of irrigation water during conventional rice production systems in the Northern IGPs. In the rice-wheat system water requirement through irrigation in the wheat crop is less (300-400 mm) than in rice (1,500-2,000 mm) yet the water deficit, is responsible for the water table decline more in the wheat crop than rice. If rice is transplanted at the right time, the ET is almost equal to the rainfall, whereas in wheat ET is nearly four times that of rainfall and it forces them to the farmer for mining of groundwater for irrigation which is ultimately responsible for the declining of the water table in RWCS.

The management of groundwater is one of the major priorities to combat the challenging issue of water scarcity in India. Due to an over reliance on groundwater and poor alternative infrastructure in the northwest IGP, the groundwater levels are declining by 0.1 to 1.0 meters every year. This is because of the expansion in the rice area which aggravates the groundwater withdrawal for irrigation purposes. In the northwest IGP majority of the farmers used groundwater for irrigation through tube wells and submersible pumps, which has further increased production costs and challenged for sustainability of this cropping system. It was estimated that if we stopped this cropping system then a reduction in the evapotranspiration would be about 150 mm / year and ultimately reduce groundwater mining. Other options are SRI, DSR, aerobic rice, application of irrigation water through micro irrigation, FIRBs and growing short duration cultivars having less water requirement.

Development of herbicide resistance

Because of the similar cropping system over the years, we are bound to the application of similar herbicides having the same mode and mechanism of action of herbicides which, leads to the development of herbicide-resistant weeds. The continuous use of a single herbicide in rice for the control of *Echinochloa* spp. resulted in the emergence of many hardy weeds. In wheat under the RWCS, the infestation of *Phalaris minor* has increased, as rice cultivation provides favourable conditions for the germination of *P. minor* seeds. Farmers have applied herbicides with similar modes of action year after year, which resulted in strong selection pressure in the resistant biotypes, and ultimately the spread of resistance increased manifold in RWCS.

Single pre or post-emergence application of herbicide fails to control the diverse weed flora of RWCS. A combination of herbicides either in a tank mixture or in sequence is required for effective control of broad-spectrum weeds and ultimately delaying the herbicide resistance development. Therefore, for effective weed management in the long term, herbicides in mixtures and rotations having different modes and mechanisms of action should be supported. Along with herbicides multiple non-chemical weed control strategies such as stale seed bed, competitive cultivars, crop rotation, use of weed-free seed, and mechanical weeding to remove the weeds before seed setting will be required.

Residue burning

In India, a huge amount of crop residue is produced every year. These residues are used as animal feed, thatching of homes, and as a source of domestic and industrial fuel. A large portion of unused crop residues are burnt in the fields primarily to clear the left-over straw and stubbles after the harvest. Non-availability of labour, the high cost of residue removal from the field, and the increasing use of combines in harvesting the crops are the main reasons behind the burning of crop residues in the fields. Burning of crop residues causes environmental pollution, is hazardous to human health, produces greenhouse gases causing global warming, and results in the loss of plant nutrients in bulk, as a result, farmers have to apply additional fertilizers, which results in a higher cost of cultivation and also reduces the soil quality in the long run.

Residue management is the major challenge in the prevailing RWCS. Among rice and wheat residue, wheat residue is used as dry feed for animals but rice straw is generally not preferred as dry feed for animals due to its high silica content. Further, the incorporation of rice straw causes the immobilization of nitrogen due to its wider C:N ratio ultimately decreasing crop yield. Thus, the farmers generally prefer to burn *in-situ* to ensure timely wheat sowing. Burning of the residues causes environmental pollution, destroys nutrients, decreases organic matter, and finally results in the deterioration of soil health. Hence, to avoid the burning of rice residues some alternate options have been suggested by scientists to the farmers like: Crop residues used for composting, mulching, litter for dairy animals, energy production, ethanol production, biogas, and making biochar. Management of crop residues using microbial consortia under conservation based tillage practices is vital for the long term sustainability of Agriculture. Hence, burning of residues must be discouraged and utilized gainfully for conservation agriculture in improving soil health and reducing environmental pollution. Several planting technologies are available for efficient use of crop residues *in-situ*. However, they require substantial improvement for large-scale adoption by resource-poor and low skilled farmers. For example, Happy Seeder seems to be one of the potential technologies for managing crop residues. To facilitate the adoption of Happy Seeder, farmers need clear guidelines for optimum irrigation, fertilizer management, pest management and long term effects on soil health. These practices reduce emissions of harmful gases and mitigate the adverse effects of global warming.

Deterioration of soil health

The conventional puddled transplanted rice reduces the percolation loss of water, eases transplantation, and suppresses weed emergence. However, the continuous adoption of this system has resulted in several negative effects on soil health. Due to repeated puddling occurs subsurface compaction, which restricts the root growth and their distribution in succeeding crops, it also affects the organic matter oxidation, thus leading to structural degradation of the soil. The continuous RWCS is also found to disturb the nutrient balance in the rhizosphere. A decrease in soil organic carbon (SOC) of 0.9 t / ha was reported under a continuous 7 years RWCS in the IGP of India. However, there are divergent opinions regarding the organic carbon (OC) and soil fertility under the RWCS. Soil organic matter levels in some areas of the rice-wheat belt are declining only where unbalanced use of fertilizers is being practiced and very little recycling of crop residue and other organic inputs occurs. Thus, the continuous RWCS severely affects soil health.

The intensive tillage operations for seedbed preparation in RWCS are responsible for poor soil health. The production sustainability of RWCS in many locations of north-west parts of the country has been reported at risk due to poor soil health and declining water table along with inappropriate residue management leading to poor nutrient cycling. Ultimately RWCS suffers multiple nutrient deficiencies and yield decline or stagnation. However, such negative impacts can be minimized by adopting rice in combination with leguminous crops and rice–oilseed crops in rotation. In the high water availability areas shifting of rice monoculture to rice-fish farming showed positive effects on soil health. Nutrient losses through residue burning need to be stopped with residue retention on the soil surface and seeding with zero-till practice can play a significant role in soil health management. Percolation of resource conservation technologies (RCTs) for rice / wheat cultivation could be effective in improving soil health and environmental quality.

Outbreak of insect-pest

Both rice and wheat crops are grown in a lavish environment. Green crops with higher doses of N fertilizers and wet conditions because of frequent irrigations are the paradise for the outbreak of insect-pests. Further, farmers acting as per the advice of the dealers increases the complexity of the system and this effect is further compounded by the effect of the monoculture system. The breeders must develop some new more tolerant crop cultivars so that new insect-pest and diseases are not able to affect markedly the grain yields.

Poor income

Degradation of the soil structure, formation of hardpan, and declining underground water table along with outbreak of insect-pests, diseases, and weed pressure usually result in lowered crop productivity in RWCS. Sometimes, adverse climatic conditions, poor soil health, deeper underground water tables, and poor quality underground water are responsible for poor yields and income.

Declining water productivity

Currently decrease in water productivity of RWCS in different agro-climatic zones of the country has been reported by many researchers. Decreased water productivity along with depletion of the water table can hamper the objective of sufficient grain production in the future. The improvement in water productivity will be achieved by modification in sowing options as well as the appropriate management of irrigation water by choosing the most suitable irrigation method. Technologies such as alternate wetting and drying (AWD), a system of rice intensification (SRI), bed planting, DSR, unpuddled transplanted rice, and DSR with straw mulching would be effective approaches to increase water productivity without much effect on the rice yield. Water-saving in AWD method is attributed to a reduction in seepage and drainage losses. This practice of irrigation is usually applied to DSR in which water required for raising the nursery and transplanting the rice is eliminated. Agronomical practices such as wheat seeding with zero-till drill / happy seeder apply water through furrow irrigated raised bed increase the yield and water productivity than the conventional method of wheat establishment.

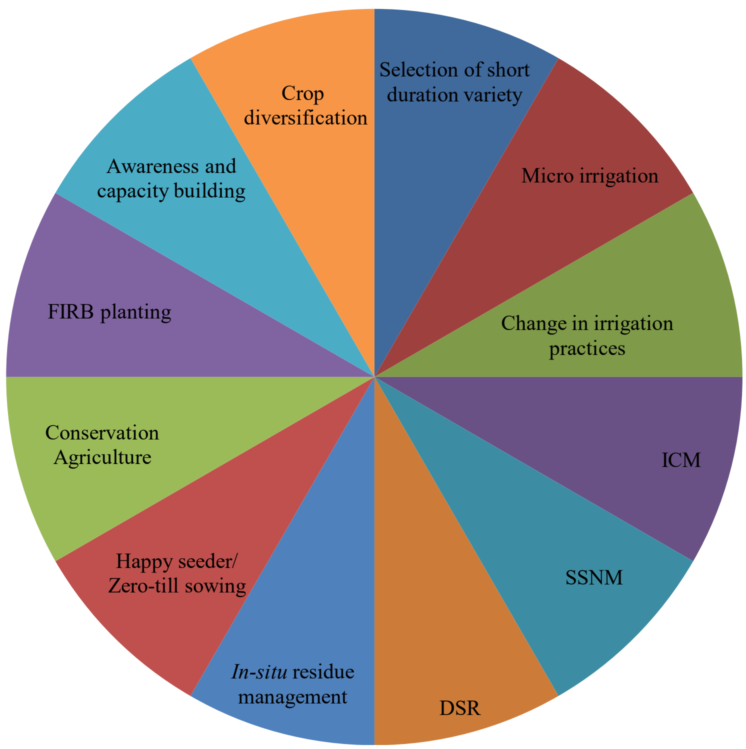

Fig. 2. Management options to overcome the drawback of RWCS

Conclusion

RWCS contributes a major portion to food security. But with time, the RWCS has faced many sustainability issues, such as depletion of soil health, declining groundwater table, water productivity, factor productivity, and environmental degradation. Therefore, there is a need to shift from the traditional RWCS to CA and adopt the need based best suitable practices for sustainable crop production.