Cropping System for Sustainable Agriculture Under Red-Laterite Zone

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There is currently a demand to grow more crops in less area as a result of urbanization's reduction of agricultural land. As a result, soil fertility is gradually declining. To maintain soil fertility, various management methods are used in modern times. Agriculture is undoubtedly the backbone of any developing country like India. It is the prime source of food-fodder-fibre-fuel-fruit-flower-fish and timber and provides raw materials to many large- and small-scale industries. A lion's share of the country's mammoth population depends directly or indirectly on agriculture. Being the largest private enterprise in India it contributes 17.6% of national GDP. The green revolution in mid-sixties, steered by research based new technological development involving new materials, methods and ways of organizing farm inputs and the government policy, transformed the agriculture dramatically. As a result, the output exhibited manifold increase in production and productivity. But this development is not spread through-out the country in equal manner. The red and lateritic zone (RLZ) of Eastern India comprised of South-West West Bengal, western Odisha and almost entire state of Jahrkhand. It occupies dismally a low position in respect of yield levels in comparison to many other parts of the country. The dismal situation regarding the low position in respect of yield levels is attributed to poor input use efficiency, soil degradation such as erosion, decline of soil organic carbon content, nitrate transfer to ground and surface water, biodiversity erosion and above all, deceleration of total factor productivity. Suitable and time bound cropping system become an important factor for higher crop production per unit area of this region. A cropping system refers to the type and sequence of crops grown and practices used for growing them. It encompasses all cropping sequences practiced over space and time based on the available technologies of crop production. This is an integrated part of farming system which is a set of activities that farmers execute in their farms under their resources and circumstances to maximize the productivity and net farm income on a sustainable basis. This is considered a powerful tool for natural and crop resource management in extreme rainfed and drought prone area of developing countries such as India. Cropping system under farming system, a multi-disciplinary whole-farm approach and very effective in solving the problems of small and marginal farmers particularly in red-latertic belt of west bengal and adjoining state. The approach aims at increasing income and employment from small-holdings by integrating various farm enterprises and recycling crop residues and by-products within the farm itself. The need for cropping systems in the present scenario is mainly due to high cost of farm inputs, fluctuation in the market price of farm produce, risk in crop harvest due to climatic vagaries and biotic factors. Environmental degradation, depletion in soil fertility and productivity, unstable income of the farmer, fragmentation of holdings and low standard of living add to the intensity of the problem. Cropping systems have been traditionally structured to maximize crop yields. Now, there is a strong need to design cropping systems which take into consideration the emerging social, economic, and ecological or environmental concerns. Conserving soil and water and maintaining long-term soil productivity depend largely on the management of cropping systems, which influence the magnitude of soil erosion and soil organic matter dynamics. While highly degraded lands may require the land conversion to non-agricultural systems (e.g., forest, perennial grass) for their restoration, prudently chosen and properly managed cropping systems can maintain or even improve soil productivity and restore moderately degraded lands by improving soil resilience. The soil and agro-climatic conditions of the red and lateritic belt are unique, and the rice-based cropping system is predominant in the region. The improvement of irrigation facilities and adaptation of HYVs and hybrids attracted farmers to adopt a rice–rice cropping system. Crop diversification is an important option in sustainable agricultural systems.

Cropping system and sustainable agriculture

As the world population, particularly that of developing countries, is increasing with an alarming rate, there is a pressure on the agriculturists to continue to feed this ever-increasing population. But during recent year, the productivity has remained stagnant and, in many cases, a gradual decline has been observed. More over the indiscriminate use of chemical fertilizer and pesticides have posed a new threat to the environment and soil ecosystem. Arsenic problem in few pockets of West Bengal and other parts of India is a good example. In our mind few questions raised that, how we can conserve the natural ecosystem without further decline in productivity and ecological situation. Good cropping systems with effective sustainable agriculture become a good answer. Sustainable agriculture as such is the successful management of resources for agriculture to satisfied changing to human needs while maintaining or enhancing the quality of environment and conserving natural resources. The modern agricultural practices which are heavily dependent on the use of chemical pesticides, inorganic fertilizers and growth regulators has raised the agricultural production manifold but at the cost of resource depletion, environmental deterioration and loss of crop diversity. Therefore it was realized that the modern agriculture is not sustainable in long run, hence the concept of effective cropping system with sustainable agriculture practice emerged, which not only emphasizes on the conservation of the natural resources but also maintains the quality of environment with effective cropping pattern etc. Sustainable agriculture is a holistic approach having many facts. One of them is cropping systems, a non-input resource which may lead to sustainable agriculture. Intensification of Rice-fallow in red-laterite belt by inclusion of suitable crops was one the major challenges due to very limited options for introduction of new crops. But, in recent times, cropping system intensification by pulses is facing a bit impediment due to ill impacts of climate change like rising temperatures, unpredictable monsoons as well as severe disease pest infestation. Venture with vegetables has already shown the troubles related to availability of enough water during post monsoon seasons in RLZ. The landscape of this region is mostly undulating with drainage lines and land near streams comprising lowlands (‘*bohal*’) which rise to local uplands (‘*tanr*’) with relief typically <30 m. Hydrologically, uplands are recharge areas whereas lowlands are local discharge areas for seasonally recharged shallow ground-water (Brahmachari *et al*., 2019). The narrow band of medium lowlands (‘*kanali*’) between them is a discharge area. The east India plateau is characterized by endemic poverty, food insecurity, comparatively low agricultural productivity and lack of irrigation infrastructure. Rice is the staple food crop and traditional cropping is typically mono-cropped rice production. *Bohal* is generally used for cultivation of rice. But with the increasing food demand, the medium uplands (‘*baid*’) of this region is now extensively used for rice cultivation. The region receives a high amount of rainfall with “low productivity” because soils are acid and infertile with low water holding capacity (Manivannan *et al*., 2017). For this, cultivation of rice in medium uplands is risky job and poorly suited to traditional rice production systems of this RLZ. Intensification of Rice-fallow in red-laterite belt by inclusion of suitable crops was one the major challenges due to very limited options for introduction of new crops (Brahmachari *et al*., 2019).

Intensification of existing cropping system of RLZ of eastern India needs a holistic approach from selection of land to value addition of final products. The existing cropping system in RLZ is mainly rice based where the farmer generally seeds rice at the onset of monsoon and reaps the harvest at the beginning of winter. Most of the land here remains fallow due to various biophysical constraints like high evapo-transpiration during summer and winter, meagre soil fertility and water holding capacity, erratic rainfall and less adoption of modern agro-techniques by the resource challenged peasants. Depending on the resources and technology available, different types of cropping systems may be adopt as per limitation of cultivation in different field, these are:

- **Monocropping or single cropping:** Mono-cropping refers to growing only one crop on a particular land year after year or practice of growing only one crop in a piece of land year after year e.g., growing only rabbi crops in dry lands or only said crops in diary lands (Lands situated in river basins which often remain flooded during rainy season). This is due to climatologically and socio-economic conditions or due to specialization of a farmer in growing a particular crop. Groundnut or cotton or sorghum is grown year due to limitation of rainfall. Flue-cured tobacco is grown in Günter (A.P.) due to specialization of a farmer in growing a particular crop. Rice crop is grown, as it is not possible to grow any other crops, in canal irrigated areas, and under water logged conditions.

- **Multiple cropping or poly cropping:** It is a cropping system where two or three crops are gown annually on the same piece of land using high input without affecting basic fertility of the soil. It is the intensification of cropping in time and space dimensions i.e. more number of crops within a year and more number of crops on the same piece of land at any given period. It includes inter-cropping, mixed cropping and sequence cropping. Under present context multiples cropping is a philosophy of maximum crop production per acre of land with minimum of soil deterioration. Few examples are:
- Rice-potato-green gram.
- Rice-mustard-maize.
- Rice-potato-sesame.
- Jute-rice-potato.

These patterns of cropping system should be very sound, so that we could sustain our soil and environment health without compromising per unit productivity and farmer or growers' income. Some of the areas where cropping system can be very effective component of sustainable agriculture, are mainly crop diversification, pest and disease management, nitrate pollution management, tillage and seed bed preparation management, water and nutrient management.

Crop diversification

Crop diversification is important factor for enhancing crop production and maintaining the sustainability. Crop rotation, mixed cropping and intensive cropping is the methods of crop diversification which not only enhances yield but also reduce the erosion. Crop rotation which refers to the alternate growing of crops is important for successful sustainable farming (Mukherjee, 2022). Crop rotation practices are not only important for soil fertility management but are also helpful in weed, pest and disease control. In any rotation, leguminous crops are essential for nitrogen supplement to the soil. Mixed cropping with leguminous crops increases the yield of non-leguminous crop therefore it is necessary for the success of sustainable agriculture. In intensive cropping a number of crops are grown simultaneously in the same piece of land in one agricultural year. Multiple cropping and relay cropping are the examples of intensive cropping.

Cropping system for disease, pest and weed management

Adoption of improved cropping system has considerably reduced the use of pesticides. In modern agriculture practices the over use of chemical pesticides has led to the problem of pesticide resistance and pest resurgence. Besides this, many of the pesticides are non-biodegradable causing the problem of environmental pollution. This has led to the emergence of the concept of Integrated Pest Management (IPM). It refers to an ecological approach of pest management in which all available necessary techniques are practiced in a unified programme so that pest population can be managed in such a manner that economic damage is averted and adverse effects are minimized. It includes mechanical, physical, cultural, biological and chemical methods. In addition to these methods, sometimes friendly insects and spiders are also encouraged. Spiders are farmer friendly as they destroy pests in many crops especially rice. Most common of them are wolf spider, sack spider, diver spider, orb spider and the jumping spider. Besides these, botanical pesticides (derived from plants) are used to control the pests and diseases. A pigeonpea + sorgum intercropping system extensively practices in Karnataka, Maharashtra and Andhra Pradesh has considerably decreased the incidence of root rot of cotton due to *Rhizoctonia solani*. Similarly, incidence of top borer in sugarcane was greatly reduced when coriander was intercropped with sugarcane.

Weed control include cultural, physical, biological and chemical methods. In sustainable agriculture cultural, physical and biological methods are at priority. Weeds are generally controlled by rotation, tillage and hand-weeding (Mukherjee, 2005). Chemical weedicides are also used to control the weeds if the above methods fail to overcome the problem of weeds. However, in sustainable agriculture weeds are often tolerated and encouraged up to some extent as weeds play valuable function like nutrient cycling, disease and pest control, soil and moisture conservation and organic matter improvement as green manure. Jonson grass (*Sorghum helpense*) a predominant weed in continuous maize cultivation was controlled by rotating with cotton. Similarly, nut grass biomass was reduced in sesame – wheat followed by sesame – wheat –green gram as compared to pigeonpea wheat , greengram sequence (Bhan *et al*. 1998). In maize – potato cropping system growing of purlemllet or sesame (for green manure) during summer was found effective in reducing *Cyperus rotendus* population is succeeding maize and potato. Intercropping systems have also been found to suppress weeds through formation of canopies due to competitive planting pattern and thus provide an opportunity to utilize cropping system as a tool in weed management with non-chemical means. Pigeonpea + sorghum intercropping system which is extensively practiced in Karnataka, Maharashtra and Andhra Pradesh is known to reduce weed intensity apart from efficient land utilization. It is also reported that inter cropping systems based on sorghum reduced weed growth by 25% more efficiently than sole crop system.

Nitrate pollution management

Pollution of ground water owing to leaching of nitrates is relatively a new concern in India. At such low rates of N-fertilizer use prevalent in the country, nitrate leaching is not likely to pose serious problems in most farming situations. However, increase in NO_3-N content of shallow wells has been registered in the areas where heavily fertilized and irrigated cropping systems predominate. In Ludhiana district of Punjab, average NO_3-content of shallow wells increased from 0.42 to 2.29 mg/litre during 1975-88 (Reddy, 1999). Fertilizer management practice, season, frequency and depth of irrigation, depth of the soil and rooting pattern of crops are most important factors influencing nitrate pollution. The same increased rapidly with increasing use of N fertilizers. Choice of appropriate cropping systems and management practices minimize nitrate leaching besides improving N use efficiency. Legume inter cropping in cereals grown with wider row reduces nitrate leaching. Parallel multiple cropping (a system of growing crops having variable growth habit with minimum competition) of sugarcane and black gram and that of pigeonpea and maize resulted in low NO_3-N content in soil profile as compared to sole cropping. As a crop management strategy to minimize NO_3 leaching it has been suggested to delay large amount of N applications until the crop can utilize it and to avoid irrigation when large amounts of NO_3-N is present in the root zone.

Conservation tillage

Tillage practices in sustainable agriculture aims at reducing soil degradation and losses by erosion. A common way is to provide optimal condition for beneficial soil organisms, thereby enhancing organic matter decomposition and nutrient cycling. Managing the top 8 cm of soil is vital because most of the biological activity, micro-organisms and organic matter are found in this soil layer. Therefore, conservation tillage is adopted in place of conventional tillage under major cropping system. Conservation tillage is disturbing the soil to the minimum extent necessary and leaving crop residues on the soil. Minimum tillage and Zero tillage are the types of conservation tillage which reduce soil loss up to 99% over convention tillage (Mukherjee, 2013). In minimum tillage, the tillage practices are reduced to minimum extent for ensuring (improved soil condition due to decomposition of plant residues in situ) a good seed bed, rapid germination and favourable growing condition, whereas the zero tillage is an extreme form of minimum tillage where primary tillage (opening of the compact soil with the help of different ploughs) is completely avoided and secondary tillage (lighter or finer operations performed an the soil after primary tillage) is confined to seed bed preparation in the row zone only. Zero tilled soils are homogenous in structure with more number of earthworms. There is increase in organic matter content due to less mineralization. Surface runoff is reduced owing to presence of mulch. In most cases, conservation tillage reduces soil loss by 50% over conventional tillage. Moreover, conservation tillage maintains the organic matter content of the soil and prevents the removal of nutrients from soil through rainwater. Conservation tillage also causes an increase in microbial and earthworms' population in the soil. In rice-wheat system high intensity deep puddling has been found to reduce drainage losses of water and fertilizer nutrients and favour rice growth in most soils (Saha *et al*., 2023). However, destruction of soil aggregates due to puddling in rice results in poor tilth, and increased soil strength in surface sub-surface layers, decrease hydraulic conductivity and infiltration and inadequate charging of the soil profile for the crop following rice. These unfavorable soil conditions reduce yield of wheat following rice than that following maize. Wheat rooting is often restricted in soils after puddling rice, which is also attributable to reduced sub-surface layers, which continue to remain wet and anaerobic long after the harvest of submerged puddled paddy. In coarse soils, tillage for rice-wheat sequence may be optimized by high intensity puddling for rice and high intensity shallow tillage for wheat, as deep tillage for the latter resulted in higher drainage losses of water and fertilizers. In maize-wheat system, some agronomists have reported better root development with deep ploughings (45cms) in a sandy loam alluvial soil, resulting in higher grain of maize as well as wheat, compared to 25 cm ploughings. Varying the number of tillage operations either in maize or wheat did not produce significant differences in the yields. However, repeated tillage increased cost of cultivation and thereby, reduced net return to the system. In vertisols rainy season sorghum + pigeon pea inter cropping system, as shallow tillage enable storage of more soil water than traditional flat bad fallow. Adoption of zero tillage play vital role for sustaining agricultural productivity in favorable soil system.

Water management through efficient cropping system

Water management is key to the success of sustainable agriculture under various cropping system in India and particularly in West Bengal, as water is an important natural resource. Water management can be divided into rain water management and irrigation water management. The important aspects of rain water management are water harvesting, supplemental irrigation and reduction of evapo-transpiration. Irrigation water management involves scheduling irrigation at appropriate time with adequate quantity of water without causing water logging, soil salinity and alkalinity. Irrigation water is a costly and scarce resource and its availability for agriculture is expected to further go down due to increase by generic and environment manipulation of the crops, it can also be increased by decreasing the evapo-transpiration and other losses of water, such as conveyance, application, water use efficiency which can be increased by identification of appropriate crop combinations in various system. More remunerative and less water consuming crop rotations have been standardized at different locations in the country. Agronomists have found that rice-potato-green gram rotations were more viable sequences under lesser water input at Memgri in west Bengal. At Kharagupur, rice-wheat, rice-mustard and rice-potato were viable sequences under lesser input (Mukherjee, 2019). Substitution of sugarcane, which is high water demanding crop for Maharashtra, it was found that per-monsoom groundnut – rabi sorghum sequence was not only highly remunerative (Rs.23,100 net returns) with a cost: benefit ratio of 1:2.9 but also highest water expense efficient (342 mm/ha) as well as production efficient (Rs.96/ha/day) (Yadav *et al*., 1998). Under limited water supply, however, rice-gram-green gram and rice-mustard-green gram have been found suitable. In north western plains, under annual supply of 10 irrigation, maize-wheat system gives the maximum net returns with minimum water expense. Maize + cowpea (fodder) – toria-wheat system followed it closely. Based on research, during last 50 years it has been established that culture of crops such as legumes which have dense canopy and deep root system, green manure crops and densely populated crops, during rainy season reduced soil and water losses to significant extent. In that context, alley cropping for adding foliage as organic mulch to conserve moisture holds promise in sorghum (F) – wheat rotation. Studies on moisture conservation at Jodhpur on shallow loam soil receiving bunding increased soil moisture content by 50 to 75% (Yadav *et al.*, 1998).

Nutrient management through efficient cropping schemes

Indiscriminate use of chemical fertilizers in modern agriculture to enhance the crop yield has abused the land resources resulting into stagnation in food grain production. Therefore Integrated Nutrient Management (INM) is key to success of sustainable agriculture. Integrated nutrient management which emphasizes on the use of renewable sources of nutrients ameliorates the soil health in long run (Mukherjee, 2014). Therefore, it ensures the concept of sustainability in agriculture. In integrated nutrient management all the possible sources of nutrients are applied based on economic consideration and the balance required for the crop is supplemented with chemical fertilizers. The sources include manures, green manures, compost, vermin-compost, bio-fertilizers and concentrated organic manures. Organic fertilizers have a slower action but they supply available nitrogen over a longer period of time. Moreover, they protect useful flora and fauna of the soil, ameliorate yields and quality of products. Since there is increase in soil fertility the biological activity is maintained intact. Based on results of Long Term Fertilizer Experiments, which have been reviewed recently and information generated under cropping systems and other scattered studies a few examples are cited below how the efficiency of nitrogen, phosphorous and potassium have been increased through efficient cropping system (Reddy, 1999). In rice – potato-jute sequence, fiber yield increased markedly due to residual effect left after potato (Mukherjee, 2021). Further, at Kalyani in Rice-Potato sequence 100 kg N applied to either of the crops left residual effect equivalent to 25 and 33% of its direct effect in potato and rice, respectively on the alluvial soil. Since plant species vary in their capacity to utilize native and fertilizer P, and leave differential amount of residual P, suitable cropping pattern designing is important. In rice-wheat system, as the distinct growing environment of these crops allowed for a greater adjustment of P application rates. Solution P increased under low land rice culture owing to submergence and high temperature, though the magnitude varied widely in different soils (Mukherjee and Mandal, 2017). Because of this phenomenon, wheat responded tremendously to apply P while relatively lower response was observed in rice on the same piece of land. It has also been reported that 60kg P_2O_2/ha applied to wheat in alluvial soils of Punjab was sufficient to meet requirement of both the crops in rice – wheat system. However, later studies in Punjab indicated superiority of direct application of 30kg P_2O_2/ha each to rice and wheat over 60kg P_2O_2/ha to either of the crops (Bhan *et al.*, 1998). In view of these results, it may be concluded that adjustment of P in cropping system should not be made without specifying the soil characteristics, nature of crops in the system, their yield level , growing environment and type of fertilizers used. Nevertheless, under resource constraints, P application to wheat may be preferred over rice in rice-wheat system on marginally deficit soils. Soils highly deficit in P are exceptions where all the crops in the system may require P application at recommended. Removal of K in proportion to N is very high in cropping system particularly in those involving cereals and fodder crops. Unfortunately, application of K has not been received due attention, as most Indian soils were considered adequate in native K supply (Mukherjee, 2014 a). But due to continuous rice – wheat cropping system and multiple cropping there is severe mining of K too. In jute growing areas where rice potato jute is a common cropping system, potato suffer more K deficiency. Use of fertilizer in potato and allowing jute to meet its K demand through residual effect was found beneficial in these areas. In rice- wheat –jute system too jute received benefit from K applied to preceding rice and wheat.

Conclusion

Suitable cropping system under different zone of India in sustainable manner does not impose any harm to environment, biodiversity, and quality of agricultural crops. Producing crops sustainably increases the ability of the system to maintain stable levels of food production and quality for long term without increasing the demand and requirements of agricultural chemical inputs to control the system. Sustainable crop production deals with keeping the soil alive with organic matter, integrated pest management and reduction in usage of pesticides, protecting biodiversity, ensuring food safety and food quality, improving nutrient quality, and fertilizing the soil with organic fertilizers. This leads to lowering of greenhouse gas emission and carbon footprint of overall world. Sustainable usage of resources ensures the pollution-free environment for our future generations.

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