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Monoculture in India: Soil health, biodiversity, and sustainability perspectives

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Abstract

Monoculture in India refers to the widespread practice of growing a single crop, most notably rice and wheat over large areas, especially in states like Punjab, Haryana, and Uttar Pradesh. While it boosts short-term productivity, it has led to soil degradation, groundwater depletion, and economic vulnerability for farmers. India's monoculture system has created short-term gains but long-term ecological and economic risks. Diversification into pulses, millets, and oilseeds supported by government policy, offers a sustainable path forward. Monoculture is more preferred as compared to polyculture or oligoculture in both commercial agriculture as well as natural farming practices/organic farming practices as it allows increased ease and efficiency in planting and harvesting. In today's agriculture scenario, simple monocultures involving two or three cereal crops are more prevailing all over the world and in India, as compared to poly culture. Panigrahi *et al* conducted a remote sensing survey of Indo-gangetic plains of India and reported that rice was predominant crop covering 65.54 % followed by maize covering 11.26 % of total agricultural area of India whereas wheat covered 67.18 % of area in Rabi. Moreover, rice and/or wheat crops were components of 10 out of 13 cropping patterns identified. This is because agrotechniques developed so far, are in the form of package for intensive cereal based crop sequences. Uniform management practices from field preparation to harvesting of crop, advent of high yielding varieties, broad range of pesticides, easily available and subsidised fertilizers and irrigation gave an edge to monoculture over polyculture because in such favourable conditions monoculture proved to be more profitable as compared to polyculture.

Keywords: Monoculture, soil health, biodiversity, sustainable production, food security

Introduction

Monoculture is agricultural practice of growing a single crop, plant, or livestock species, variety, or breed in a field or farming system at a time. In polyculture more than one crop is grown in the same space at the same time. In the last half century, agriculture intensification has occurred at a faster rate in terms of dissemination of high yielding varieties, consumption of large amount of energy, more application of external inputs (fertilizers, irrigation, plant protection measures, herbicides etc), purposeful selection of single crop and varieties, which collectively disturbs the natural ecosystem and enhance the willful cultivation of agro-ecosystem (human interfered one). This led ecological implications viz., reduction in diversity of plant species, soil health deterioration, environmental pollution, depletion of available water resources, nutrients imbalances, human health issues etc. Problems associated with monoculture are to be addressed and their improvement strategies should be worked out. This chapter covers the monoculture, its ecological impact with special reference to the most prevalent monoculture of rice- wheat cropping system. Monoculture is the agricultural practice of producing or growing a single crop, plant, or livestock species, variety, or breed in a field or farming system at a time. Polyculture, where more than one crop is grown in the same space at the same time, is the alternative to monoculture.

Agriculture has modified natural ecosystems in a number of different ways. In agricultural systems, biodiversity performs ecosystem services beyond production of food, fiber, fuel, and income. Examples include recycling of nutrients, control of local microclimate, regulation of local hydrological processes, regulation of the abundance of undesirable organisms, and detoxification of noxious chemicals (Alteiri) but the species richness/biodiversity is purposefully reduce to accommodate the desired cultured species. Due to biological simplification, these natural services of an ecosystem are lost. Then the need to

supply crops with costly external inputs is increased because agroecosystems deprived of basic regulating functional components lack the capacity to sponsor their own soil fertility and pest regulation. Diversion of nutrients, energy, water and other natural resources is towards commercially desirable species occurred into abundance of single crop variety in a field, that is ecologically known as disproportionate and intentionally overabundance of one organism. But economically, this phenomenon serves the purpose of agriculture and this can not be displaced just for the sake of mimicking the natural ecosystem because a better measure of agricultural productivity is the amount that can be harvested and exported to cities, sustainably. Herbivores and decomposers in natural ecosystems consume much of their primary production, leaving little for harvest if selective diversion of resources is not done in favour of desired crop or animal (Altieri, 1999) ^[1]. Agriculture intensification has occurred in last half century in terms of transfer and dissemination of high yielding varieties, use of large amounts of energy, exogenous fertilizers, pesticides, and herbicides per hectare, the association of cultured crop species has been replaced by prevalent monocultures and continuous cropping of the same variety. The existence of such monocultures is maintained by elaborate plant and animal control programs to maximize protection of the monocultured crop. Simultaneously, such monocultures serve as huge opportunities to exploit a vast pool of nutrients and energy not only by humans, but also by competitors (weeds, insects, and pathogens) which are able to resist the artificial eradication schemes. Matson *et al* 1997 ^[13] has discussed the following biological consequences of agricultural intensification:

Pest complex refers to the community composition of herbivorous insects, their natural enemies (predators and parasites) and microbial community attacking crops. Strong favour towards crop specific herbivorous pest is trend in monoculture whereas low abundance of specific pests due to severe competition from other insects, higher predation rate and higher ratio of natural enemies to herbivores is characteristic of polyculture. Microbial pathogens - crop diversification can either discourage or inhibit pathogen growth according to microclimatic conditions created by crop which can either favour or discourage development of severity of plant diseases. Virus infestation is obviously less in polyculture because insect vector tend to be found at lower incidence. Crop rotations are devised so that cultivation of one crop potentiates the growth of a particular succeeding crop so that a successional sequence is used, artificially, to enhance productivity for human use. Ecological successions have usually been replaced by crop rotations. Intercropping of cereals with shrub or tree crops achieves spatially what rotations achieve temporally in a given area. Lands used for the production of annual crops or animal forage are kept in the early productive stage of a succession so that energy and nutrients are used more for structural plant growth and reproductive structures than for the maintenance of mature plants. Even where fruits of long-lived plants constitute the crop, as in orchard tree fruits and berry crops, succession is held in check and the diversity of associated species is kept low.

Agriculture as an applied ecology

Agriculture is also an applied ecology therefore, it can be examined through application of knowledge about organism

and their environment. In an ecosystem whether it is natural or managed by humans (i.e. agroecosystem) ecological principles will be implied in a similar fashion. Evolution of a natural ecosystem involves several organisms and environment altogether and core mechanism is continuous interaction and adaptation of organism to the dynamic environment which is also aided by invasion of new organisms and species and finally there is a climax community. In any ecosystem individuals of a species exist in one or more populations and the different species which interact biologically will form an ecological community (Thomas and Kevan, 1993) ^[15]. The characteristic feature of climax community in a natural ecosystem that it is diverse as much as possible. Ecological biodiversity can be explained on the basis of principle, namely continuous regulation of of a species in terms of their abundance (how many individuals) and distribution (where they occur) as high diversity ecosystem will have more species occurring more frequently among the habitats than ecosystems of low diversity. Biodiversity confers stability and resilience to certain level of disturbances (various biotic and abiotic factors) to a community. An agroecosystem is also governed by same principles of ecology having same chain of evolution except a small modification that is human intervention in natural ecosystem mechanisms. This human intervention mechanism involves:

1. Suppression of dominant but undesirable organisms insect-pest and weeds, and disease propagules.
2. Selection of desirable plants and animals.
3. Diversion of maximum resources towards the selected desirable species to get maximum output.

Therefore, some ecological events are modified such as a plant species is artificially protected from various biotic and abiotic stresses by using agrochemicals and provided an edge by modifying the growing conditions as required (such as submerged and puddled conditions for rice even in unsuitable soil and water availability conditions) thus adaptation is replaced by false adaptation which simply means organism (plant or livestock) is not or partially confronted with real ambience (including soil moisture, competition by insect-pests and weeds, and abiotic stresses such as drought, heat, cold, frost etc.). Moreover, biotype and succession events are completely absent or checked at a certain level.

Selection Mechanism

Selection of a species is toward achieving maximum commercially desired part of organism body for example in cereals higher grain yield as compared to vegetative parts. Other selection criteria are to enable the species to grow in different environments and resist against different stresses such as drought resistance, insect-pest resistance diseases resistance, cold hardiness and so on. Thus, artificial selection for narrow array of goals characterises an agroecosystem whereas, natural selection, emphasises upon variability and reproductive fitness in a natural ecosystem. Group selection, which is supposedly absent in nature, would be the most appropriate type of selection for improving the productivity and uniformity of agricultural and forestry crops (Thomas and Kevan, 1993) ^[15].

Recycling of nutrients

Nutrient and organic matter recycling in a natural ecosystem is never complete rather it is a continuous process. Inputs are soil mineralization, nitrogen fixation, and direct

importation by migratory animals. Processes such as denitrification, leaching, and export by migratory animals, remove nutrients from the systems. However, this system of nutrient cycling is altered in an agroecosystem owing to its some characteristic features like i) removal of crop residues from the field. ii) Input is aided by heavy application of fertilizers. iii) As already known, farms exist to export the agricultural commodities for human consumption and there is little recycling between human settlements and farms. iv) uncoupling of animal production from crop production. v) tillage of soil in cropping area interferes with naturally occurring processes in soil.

Rice-Wheat Cropping System: Most R-W systems are located in South and East Asia within subtropical to warm temperate climates, characterized by cool, dry winters, and warm, wet summer. Indo-gangetic plains constitute 85% of total area RWCS of South Asia i.e. 13 m ha in which Indian part of IGP comprises about 10 m ha. About 75% of the total rice area and 63% of the wheat area in the IGP is under RWCS. About $\frac{3}{4}$ of total cereal production comes from RWCS in Punjab. RWCS, which is a long established grain production system of China, is quite new to Indian Subcontinent and started only in late 1960s with the introduction of dwarf wheat from CIMMYT, Mexico, which requires a lower temperature (mean below 230C) for good

germination than that required for traditional tall Indian wheat. Thus wheat sowings were shifted from mid-October to mid-November which provided a full extra month for the preceding rainy season crop. This provided enough time for rice to mature; high yielding varieties for which were already available. This set in the RWCS in the Indo-Gangetic plains (IGP) of the Indian subcontinent i.e. Punjab, Haryana and western UP (traditionally wheat growing regions) and Bihar and West Bengal (traditionally rice growing regions) were turned into rice-wheat regions. The green revolution technologies led to the emergence of rice-wheat as the major cropping systems in the IGP, which now ranks first among 30 major cropping systems of India. Panigrahi *et al* carried out a study for carried out to delineate the existing cropping systems in the Indo-Gangetic Plains (IGP) ^[14] using 10 day composite SPOT VEGETATION (VGT) NDVI data. The analysis of seasonal cropping pattern showed that, during kharif season, in IGP states rice is the major crop covering about 65.5% of the agricultural area of the plain. During rabi season, wheat is the major crop of the IGP except West Bengal. The total area covered by the crop is 67% of the agricultural area of the IGP. The crop rotations and their spatial distribution obtained by combining the kharif, rabi and summer crops of all the states are shown in Fig. 2. Rice and/or wheat is component of 11 out of 12 cropping systems.

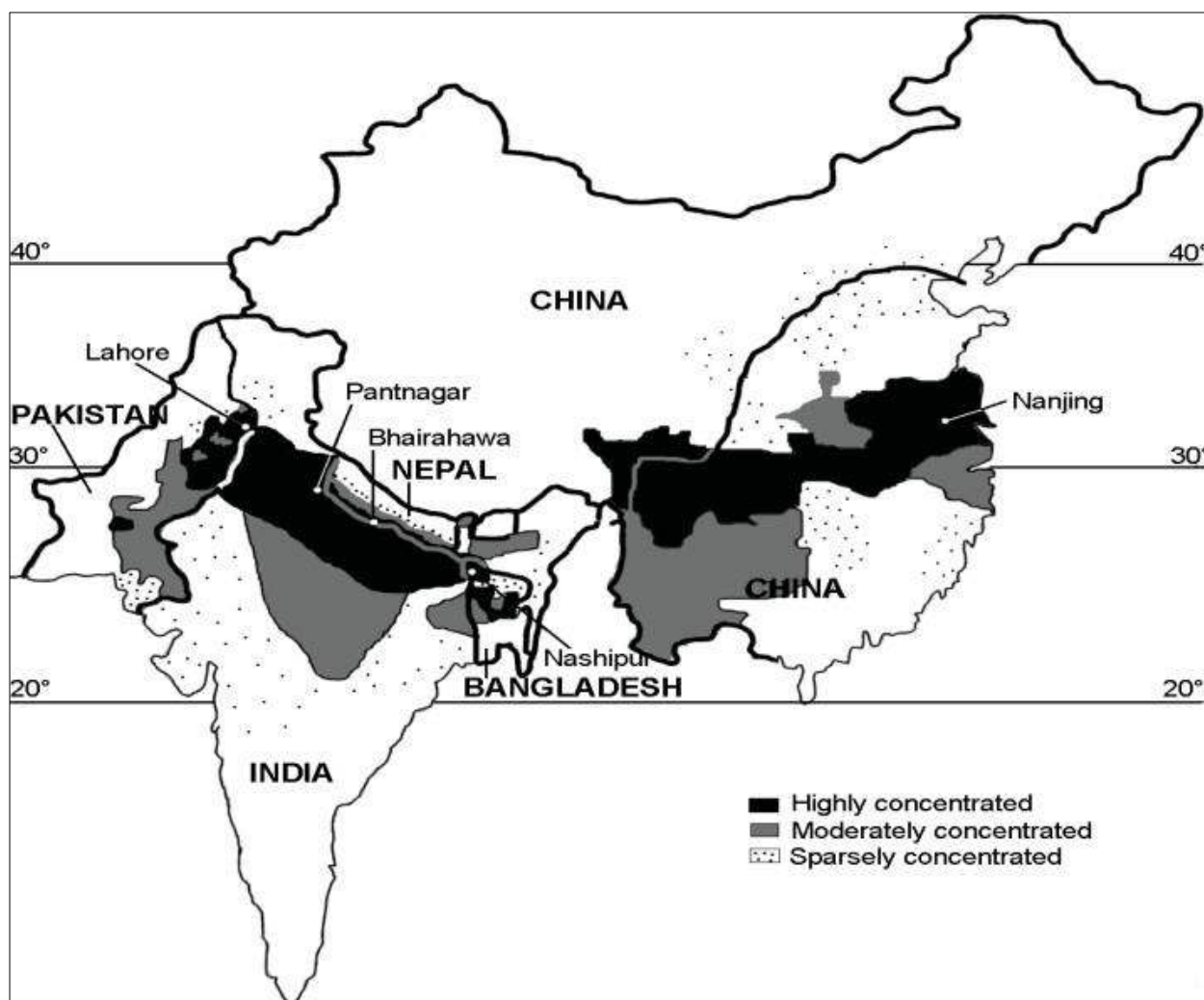


Fig 1: Distribution of R-W production areas in South Asia and China

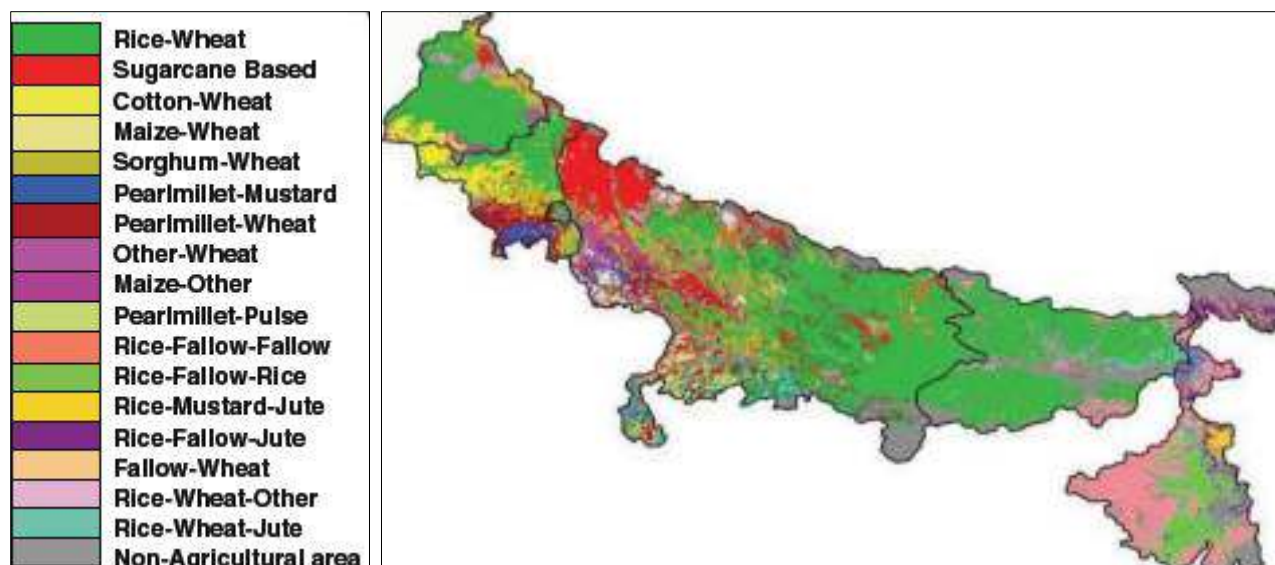


Fig 2: Major Cropping Systems of Indo-Gangetic plain derived from Multi-date SPOT VGT NDVI data

Characteristics of Rice-Wheat cropping system the dry-wet-dry transition

The traditional technique of rice culture involves puddling the soil to form a saturated root zone for the ready establishment of transplanted seedlings above a compacted subsoil layer that reduces seepage of standing water from the paddy during the crop cycle. Wheat and other crops in the system cannot tolerate the anaerobic conditions to which rice is well adapted, however, so the dominating feature of current R-W systems becomes the annual conversion of soil from aerobic to anaerobic and then back to aerobic conditions. These conversions have significant effects on the physical, chemical, and biological status of soils that determine growing conditions for all crops in the system. Thus, Seasonal wet and dry crop Cycles over a long period have important implications for management practices, including crop establishment and nutrient, water and weed management in RW system.

Increased use of reliance on inorganic fertilizers

Intensification and mechanization of RWS in Punjab, Haryana, and some parts of Uttar Pradesh had reduced cattle population. This is due to lack of demand for animal power and conversion of pastures and other areas under fodder crops into agricultural lands. As a result, use of organic manure for rice and wheat crops has drastically reduced over the period in these states as well as in eastern India. Further, availability of chemical fertilizers at subsidized cost is also a principal factor for the negligence of conventional organic manures under intensive RWS.

Modern rice and wheat varieties are highly responsive to chemical fertilizers. Therefore, use of fertilizers has increased tremendously for rice and wheat in the intensive rice-wheat belts. Use of chemical fertilizers is still low in Bihar as adoption of HYV is low with less proportion of area under irrigation. In West Bengal, fertilizer use increased after the 1980s as modern varieties started spreading.

Asymmetry of planting schedules

The reasons for late planting of wheat in the rice-wheat system include late harvest of the preceding rice crop; growing of long duration, photosensitive, high quality

basmati rice that matures late; a long turn around time between rice harvest and wheat planting; and growing of a short duration third crop after rice. Measures to avoid late planting include practicing zero tillage in wheat and direct sowing of rice.

Declining water availability and ground water depletion

A large amount of water is used to maintain flooding in rice field. Rice grown by traditional practice requires approximately 1500 mm of water during a season. In addition, around 50 mm of water is required to grow seedling to the transplanting stage. The actual amount of water applied by farmer is much higher than recommended. Availability of sufficient irrigation water has made the RW system in the NW IGP a typical example of a highly productive system in non-ideal rice soils (porous, coarse and highly permeable). Paddy consumes about 62 % and Wheat 20% of total irrigation water requirement of Punjab state. Four decades of RW system have depleted the water resources in this region to a great extent. In Punjab alone there is a water shortage of 1.2 mha meters annually (Hira, 2009) [9]. The excess demand for water is being met through overexploitation of groundwater, leading to a decline in the water table. Only 23 % of area in Punjab is irrigated by canals and for remaining 77 % of area tubewells have become a reliable source. Ground water depletion in Punjab as well as other parts of NW zone is at the rate of 70 to 100 cm/year. The areas having water table below 9 m increased from 3% in 1973 to about 90% in 2004 and almost 100% in 2010 in RWCS zones of India (Kumar *et al*).

Deteriorating soil health

Water Logging, Soil salinity and alkalinity

Water logging is caused by seepage of water from canal system and over irrigation and submergence requirement of rice crop cause waterlogging which delayed planting of wheat in rotation with rice because soil is not in condition for field preparation for wheat sowing immediately after rice harvesting. Further, the farmers in North-west India are facing a situation in which they have to deal with salt volumes that are harmful for the water uptake of crops. Soil salinity may occur due to the two reasons:

1. Source of salt content in surface soil is use of poor quality ground water and heavy irrigation in semi-arid areas which helps to sub-soil salt content to come on surface soil layers.
2. Puddled soil conditions reduce permeability to water so salt can not be leached down beyond the root zone.
3. In some irrigate areas, considerable recharge of ground water leads to waterlogging and capillary salinization.

Dutta and Jong (2002) ^[7] conducted a case study in gohana sub-division of Sonapat district of Haryana and concluded that water logging and salinity problem started around 1970, and it took 4 years until the first 5% of the land was affected, another seven years for the next 5% and until 1995 about 35% of the area was affected from salinity. In area situated on the bank of canal 50% of the land area was affected from salinity in 1995.

Poor soil fertility

Rice and wheat are heavy feeder of nutrients. One ton of wheat grains is estimated to remove 24.5, 3.8 and 27.3 kg N, P and K, respectively. Whereas similar production of rice grains removes 20.1 kg N, 4.9 kg P and 25.0 kg K. the rice-wheat system has not only resulted in mining of major nutrients but also caused imbalance of nutrient, leading to deteriorating soil health because nutrient applied by farmer are not in proper ratio, for example, NPK ratio in 2012- 13 was very wide i.e. 8.3:2.7:1 and Use of high analysis fertilizer with macronutrients (mostly N and P only) while neglecting micronutrient requirement. Moreover, increasing trend of burning of crop residue also leads to permanent nutrient loss from plant-soil cycle. Particularly K mining is at alarming rates because 80 to 85 % of the K absorbed by rice and wheat crop remains in straw. That's why there is a negative K balance in soil due to crop residue burning. K removal by crop residue represents approximately five times as much as is supplied by fertilizers. (Chander, 2011) ^[5]. A negative K balance can be substantially improved by returning wheat residue to soil which are now being removed mainly for dry fodder. The partial factor productivity of N, P and K for food grain production has dropped from about 81 kg grain per kg N in 1966-67 to 15 kg/kg N in 2006-07. Ladha *et al* (2003) ^[11] analyzed the data from 33 LTE of India, Nepal, China and Bangladesh. The annual yield change in rice ranged from -5.1 to 3.6% per year of average yield of respective LTE after 14 and 11 years of rice and wheat cultivation, respectively. Yield of both rice and wheat were stagnant in 75 and 85 % of LTE while 22 and 6% of LTE showed a significant decline in yield trend. On the system basis 60% of LTE had a negative yield trend with 18 % significant decline. In 90 % of LTE the fertilizer K addition were not sufficient to sustain a neutral input-output balance and all the LTE with significant yield decline had negative balance of K. in one of the LTE yield decline was arrested when Zn was applied along with NPK. micronutrient (Pusa).

Micronutrient status

Imbalanced use of macronutrient fertilizers, decreased use of organic manure, reduced recycling of crop residues, and bumper harvests in the past three decades have induced secondary and micronutrient deficiencies in the IGP. In several areas with intensive cropping, zinc (Zn) deficiency appeared initially and subsequently the deficiencies of iron

(Fe), manganese (Mn), boron (B), and molybdenum (Mo) were recorded. The severity of these deficiencies depended on the soil conditions and the crop grown. Rice crop removes larger quantities of micronutrients compared to wheat. Increase in fertility levels progressively increases the total removal of micronutrients due to increased dry matter production. The extent of micronutrient deficiency varies not only in different states and districts but also in different blocks within the same district depending upon the soil characteristics and other management conditions.

Areas of micronutrient deficiency

- Zn deficiency first appeared in rice in Uttarakhand in 1965 and then in Punjab in 1970 and now its deficiency is most widespread in India among all micronutrients.
- The extent of iron deficiency is approximately a fifth that of zinc deficiency and is largely influenced by the vast areas under alkaline to calcareous soil tracts.
- Iron deficiency is only second in importance after zinc deficiency in Punjab and Haryana.
- Manganese deficiency is in localized sites where rice-wheat crop rotation is practiced in coarse-textured soils.
- Copper deficiency is not widespread in the IGP, but deficiency based on plant analysis is higher than soil analysis. The critical limits used for soil copper or plant copper need to be re-calibrated.
- The incidence of boron deficiency was highest in the acid soils of West Bengal followed by the calcareous soils of Bihar. Deterioration of soil health in IGP tract has occurred due to the following reasons:
- Increased water logging in low lying area, canal seepage and over irrigation and increased salinity due to use of poor quality ground water and secondary salinization.
- Reduced levels and frequency of farmyard manure applications to crop fields is attributed to changes in livestock herd size and composition; and increased use of manure for household fuel.
- Fewer crop residues (incorporated into the soil or used as surface mulch) are attributed to their increased use for livestock fodder (due to reduction in grazing/pasture area); and increased burning of crop residues.
- Increased reliance on continuous rice-wheat rotations and a decline in the attractiveness of break crops are attributed to low yields and profits from break crops; and market access problems and associated policy issues.
- Intensive nutrient mining in the surface soil is attributed to restricted root growth associated with the plough pan created during puddle rice culture.
- Low application levels of inorganic fertilizers, insufficient to replace nutrients extracted during crop production.
- Use of inorganic fertilizer sources that do not contain secondary elements or micronutrients.

Yield Decline

The Green revolution that made Asia food sufficient was the result of continued research on improvement of germplasm and agronomic practices and government policies that made farmers adopt these new HYVs and new technologies. But Actual Yields (Ya) are far below Potential yield (Yp) in developing countries as compared to developed countries.

George (2014) ^[8] has given poor adoption and practice of the advances in agronomy and opting for low-risk, low-cost practices over high risk investments in labor and other inputs required for high-yield agronomy by the average developing country farmer as most common reason for large yield gaps as indicated by:

1. The PFP of fertilizer drastically declined in India from about 75 kg grain kg fertilizer between 1965 and 1980 to just 17 kg grain kg-1 fertilizer in 2009.
2. While rice is 100% irrigated in the US (Ramsey, 2010), only about 59% was irrigated in India in 2008.
3. The rice yield growth rate has been low in India; yield increased at a rate of only 46 kg ha-1 yr-1 from 1965 to 1980 as against 1.3 Mg ha-1 in India compared to a rate of 74 kg ha-1 yr-1 from 1965 to 1980 as against 4.4 Mg ha-1 in the US.

Ladha *et al* (2003) ^[11] analyzed the data from 33 LTE of India, Nepal, China and Bangladesh. The annual yield change in rice ranged from -5.1 to 3.6% per year of average yield of respective LTE after 14 and 11 years of rice and wheat cultivation, respectively. Yield of both rice and wheat were stagnant in 75 and 85 % of LTE while 22 and 6% of LTE showed a significant decline in yield trend. On the system basis 60% of LTE had a negative yield trend with 18 % significant decline. In 90 % of LTE the fertilizer K addition were not sufficient to sustain a neutral input- output balance and all the LTE with significant yield decline had negative balance of K. In one of the LTE yield decline was arrested when Zn was applied along with NPK.

Soil C status vs. Yield

Soil organic matter serves as a soil conditioner, nutrient source and substrate from microbial activity and considered as a most important basis of sustained yield. Several researches and analyses of LTE has demonstrated that although other soil properties do not show acceptable changes in LTE of RW system, in irrigated double- and triple cereal crop systems SOM appears to be increased.

However, increasing stocks of soil organic C not necessarily increase the yield and yields of rice and wheat decreased in some of the LTE instead of increasing total soil organic carbon (Ladha *et al.*, 2003) ^[11]. Cassman, 1999 has discussed the reason and concluded that the decrease in soil N supply caused by the accumulation of phenol C in the youngest humic fractions in irrigated rice systems, and that phenol enrichment results in a reduced rate of mineralization from these organic matter pools. Bronson *et al* (1998) ^[4] observed that only active fraction of SOM is important as it is directly involved on nutrient availability whereas the total SOM stocks is not of such importance.

Disposal of crop residues: The Ministry of New and Renewable Energy (MNRE, 2009), Govt. of India has estimated that about 500 Mt of crop residues are generated every year. Among different crops, cereals generate maximum residues (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt) and sugarcane (12 Mt). The cereal crops (rice, wheat, maize, millets) contribute 70% while rice crop alone contributes 34% to the crop residues and wheat ranks second with 22% of the crop residues. Generation of crop residues of cereals is also highest in Uttar Pradesh (53 Mt), followed by Punjab (44 Mt) and West Bengal (33 Mt). Traditionally crop residues have numerous competing uses such as animal feed, fodder, fuel, roof thatching, packaging and composting. The residues of cereal crops are mainly used as cattle feed. Rice straw and husk are used as domestic fuel or in boilers for parboiling rice. The remaining residues are left unused or burnt on-farm. In states like Punjab and Haryana, where crop residues of rice are not used as cattle feed, a large amount is burnt on-farm. The surplus residues i.e., total residues generated minus residues used for various purposes, are typically burnt on-farm. Estimated total amount of crop residues surplus in India is 91-141 Mt. Cereals and fibre crops contribute 58% and 23%, respectively. Out of 82 Mt surplus residues from the cereal crops, 44 Mt is from rice followed by 24.5 Mt from wheat, which is mostly burnt on-farm

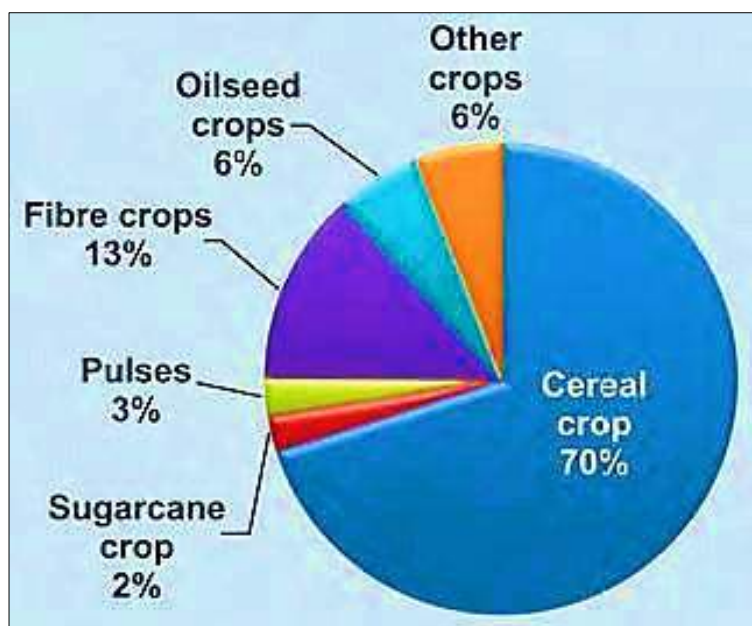


Fig 3: Residue generation by different crops in India (MNRE, 2009)

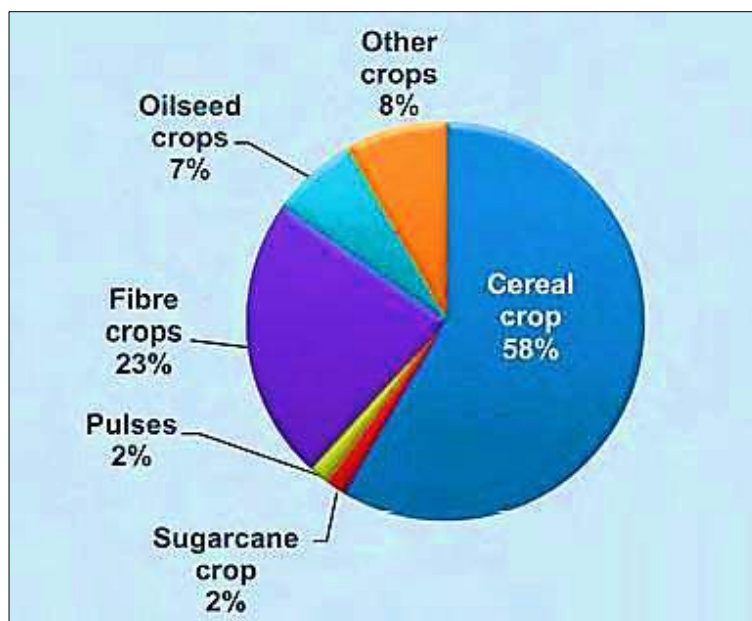


Fig 4: The share of unutilized residues in total residues generated by different crops in India (MNRE, 2009)

Reasons of burning crop residues in RWCS

However, because of increased mechanization, particularly the use of combine harvesters, declining numbers of livestock, long period required for composting and unavailability of alternative economically viable solutions, farmers are compelled to burn the residues. The number of combine harvesters in the country, particularly in the Indo-Gangetic Plains (IGP) has increased dramatically from nearly 2000 in 1986 to over 10000 in 2010. The north-western part (Punjab, Haryana and Western Uttar Pradesh) of the IGP has about 75% of the cropped area under combine harvesting. Combine harvesters are used extensively in the central and eastern Uttar Pradesh, Uttarakhand, Bihar, Rajasthan, Madhya Pradesh and in the southern states as well for harvesting rice and wheat crops. Major reasons for rapid increase in the use of combines are labour shortage, high wages during harvesting season, ease of harvesting and threshing and uncertainty of weather. On using combine harvesting; about 80% of the residues are left in the field as loose straw that finally ends up being burnt on farm.

Adverse consequences of on-farm burning of crop residues

Burning of crop residues leads to release of soot particles and smoke causing human and animal health problems. It also leads to emission of greenhouse gases namely carbon dioxide, methane and nitrous oxide, causing global warming and loss of plant nutrients like N, P, K and S. The burning of crop residues is wastage of valuable resources which could be a source of carbon, bio-active compounds, feed and energy for rural households and small industries. Heat generated from the burning of crop residues elevates soil temperature causing death of active beneficial microbial population, though the effect is temporary, as the microbes regenerate after a few days. Repeated burnings in a field, however, diminishes the microbial population permanently. The burning of crop residues immediately increases the exchangeable NH_4N and bicarbonate-extractable P content, but there is no build-up of nutrients in the profile. Long-term burning reduces total N and C, and potentially mineralizable N in the upper soil layer. The burning of

agricultural residues leads to significant emissions of chemically and radiatively important trace gases such as methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), oxides of nitrogen (NOX) and sulphur (SOX) and other hydrocarbons to the atmosphere. About 70%, 7% and 0.7% of C present in rice straw is emitted as carbon dioxide, carbon monoxide and methane, respectively, while 2% of N in straw is emitted as nitrous oxide upon burning. It also emits a large amount of particulates that are composed of a wide variety of organic and inorganic species. One ton of rice straw on burning releases about 3 kg particulate matter, 60 kg CO, 1460 kg CO_2 , 199 kg ash and 2 kg SO_2 . Besides other light hydrocarbons, volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), SOx and NOx are also emitted. These gases are of major concern for their global impact and may lead to increase in the levels of aerosols, acid deposition, increase in tropospheric ozone and depletion of the stratospheric ozone layer. These may subsequently undergo trans-boundary migration depending upon the wind speed/direction, reactions with oxidants like OH, leading to physico-chemical transformation and eventually wash out by precipitation. Many pollutants found in large quantities in biomass smoke are known or suspected carcinogens and could be a major cause of concern leading to various air-borne/lung diseases.

Weed flora shifts and herbicide resistance

In rice, excessive suppression of most dominant weed *Echinochloa* species led to occurrence of several other weeds like *Cynodon dactylon*, *Ischameum rugosum*, *Leptochloa chinensis* and *Paspalum distichum* (grasses), *Ammania baccifera*, *Ludwigia* sp., *Caesulia axillaris*, *Commelina benghalensis* and *Eclipta prostrate* (BLWs) and *Cyperus difformis*, *Cyperus iria*, *Cyperus rotundus* and *Fimbristylis milacea* (Sedges) as important and dominant weeds in rice. In wheat, *Phalaris minor*, *Cornopus Didymus*, *Melilotus* spp., *Vicia sativa*, *Lathyrus aphaca*, *Chenopodium album*, *Anagalis arvensis* and *Polygonum* spp. are the dominant weeds. The most dominant and problematic weed is *P. minor*, which was introduced in India with wheat seed

imported from Mexico in the late 1960s and soon became a major weed in wheat in the RW cropping system in the fertile and irrigated conditions of the NW IGP. The presence of this weed has been noticed in other cropping sequences also but at lower intensities. The most affected states in India are Punjab and Haryana, however, *P. minor* infestation is one of the serious causes of concern in Uttar Pradesh, Uttaranchal, Madhya Pradesh and parts of Bihar, and Himachal Pradesh, where it reduces wheat production significantly. The success of *P. minor* in the rice-wheat rotation appears to be related to high surface moisture for seedling emergence, high input levels, and a phenology which is ideally suited to the climatic conditions (Malik and Singh 1995). Yadav and Malik has mentioned the following reasons for its survival and spread in this region along with citing reasons given by Dhiman *et al* (2002)^[16]; Malik *et al.* (1998)^[12] and Malik (2003):

One reason for its continuous success is cropping pattern itself. With continuous growing of wheat, weed flora did not diversify. Diversification by growing alternate crop will make other weeds to emerge and grow, thus posing the competition to a single weed like *P. minor*. It is susceptible to solarization. Presence of water in rice fields lowers the temperature of soil, and thus helps in its survival in rice-wheat system as compared to other cropping systems.

1. Puddling helps in deep placement of seed in the soil and hence exposure to relatively lower temperature.
2. The increased and prolonged activity of alcohol dehydrogenase in *P. minor* is known to play a detoxifying role in anaerobic respiration, hence retaining viability.
3. Its tolerance to anoxia might be due to inherent ability of seed in using NO₃ as an alternate electron acceptor in Electron Transport System (ETS) with the help of nitrate reductase activity.
4. Spread of littleseed canary grass from farm to farm in contaminated wheat seed and in irrigation water particularly under canal irrigation system, farm machinery and exchange of wheat-seed amongst farmers.
5. It is quite often that most of the farmers use wheat seed for sowing purposes from their own stocks of previous years, because seed replacement with certified seed is hardly 10% each year. The seed used from farmers' own stores for sowing purpose may also contain large number of *P. minor* seed due to carelessness or ignorance in cleaning before sowing.
6. After the evolution of herbicide resistance (1992-93), this weed has flourished in the absence of serious competition from other weeds. *P. minor* is highly competitive and in most of the instances it does not allow other weeds to pose serious threat in wheat. It is evidenced by the fact that mostly broadleaf weeds appear in wheat when *Phalaris* is effectively controlled.
7. Burning of rice stubbles straw, especially after combine harvesting, appears to have reduced herbicide efficacy possibly due to increased adsorption of isoproturon on ash.
8. Continuous rotation of rice-wheat could have favoured this weed because of adequate moisture availability throughout the year.
9. Growing of short-statured high yielding varieties of wheat and increased fertilizer use will continue to favour this weed.

The herbicide isoproturon introduced to its control in 1970s proved to be a magic herbicide that ruled the wheat field for more than two decades due to its broad spectrum weed control, low cost and post emergence application. However, faulty spraying techniques, the use of lower than recommended rates, the use of less quantity of spray solution and repeated use of the herbicide year after year eventually resulted in the evolution of biotypes of *P. minor* resistant to isoproturon. The threat was further aggravated with time due to multiple resistance to alternate herbicides clodinafop and fenoxaprop and cross resistance to pinoxaden and fenoxaprop. Area under isoproturon resistant *P. minor* varies between 0.8 to 1.0 million hectares in India mainly confined to Haryana (0.5-0.6 m ha) and Punjab (0.3 m ha) (Yadav and Malik, 2005)^[16].

Climate change

Wetland rice is major source of atmospheric methane (24 %) only followed by enteric fermentation (63%). Alternate wetting and drying conditions lead to nitrous oxide emissions due to denitrification process. About 150 l of diesel is consumed per year per ha in field preparation and pumping water in conventional systems which amounts the emission of 400 kg CO₂ per ha per annum (Chauhan *et al*).

Transgenic monoculture

The global land area under transgenic crop increased 4.5 fold at one year interval i.e. 2.8 mha in 1996 to 12.8 mha in 1997 (Altieri, 2000) and in 2010 it was 150 mha. India has more than 11 mha area under Bt cotton. Transgenic crops being grown mostly are herbicide resistant maize, rice, canola, soybean and insecticide resistant cotton. Transgenic crops are grown as monoculture due to high level of uniformity in morphology and uniform management practices and ease of application of broad spectrum herbicides.

Implications of Transgenic Monoculture

Altieri has described the following ecological consequences of transgenic monoculture:

- Imbalance in composition of community.
- Increased use of broad spectrum herbicides promote herbicide resistance in weed population.
- Residual effect due to more repeated use of herbicides will narrow the choice of crops in rotation.
- HRCs will act as weed in other crop fields.
- Transfer of herbicide resistant gene from HRC to its relative weeds will give rise to "Superweed".
- Increased dominance of non-lepidopteran insects in Bt resistant crops.
- No reduction in insecticide doses as more insecticide will be needed to control other non-lepidopteran insects.
- Continuous release of Bt toxin in field will pose strong selection pressure and cause resistance in lepidopteran insects.
- Natural enemy insect which feed on insects targeted through Bt cotton will extinct due to starvation.
- Reduction in Agroecosystem complexity due to total weed removal will deprive us of certain benefits of acceptable levels of weed diversity such as soil cover reducing erosion, allelopathic effect on other weeds.

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