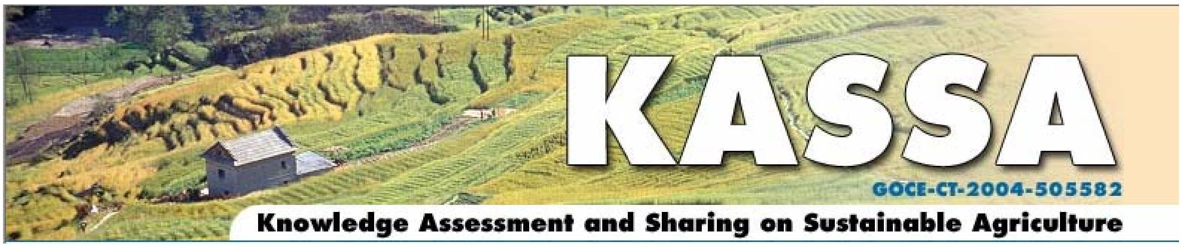

Comprehensive inventory and assessment of existing knowledge on sustainable agriculture in the Asian platform of KASSA

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1. Introduction (Description of the regions)

1.1. Indo-Gangetic Plains

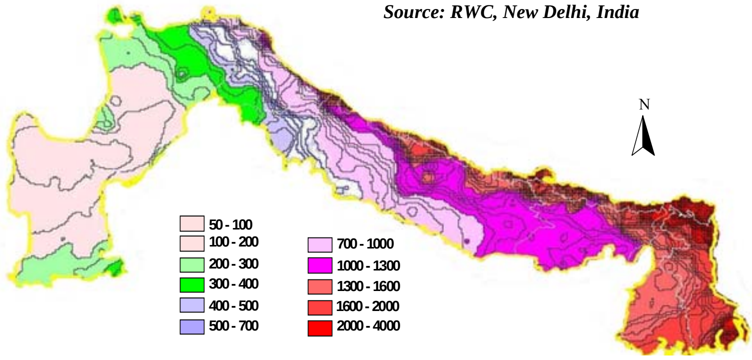
The Indo-Gangetic Plains (IGP) is a relatively homogenous ecological region in terms of vegetation but can be sub-divided into five broad transects, based primarily on physiographic and bio-climate factors. Trans-Gangetic plains (Region-1 and 2) occupy large areas of east and west Punjab and Haryana, in Pakistan and India respectively. Transect-3 and 4 include the areas of the upper and middle Gangetic plains in Uttar Pradesh (UP), Bihar, and *Terai* of Uttaranchal in India and of Nepal. Lower parts of the Gangetic Plains in West Bengal, India and parts of Bangladesh represent Transect-5 (Figure 1). IGP exist in the fertile and adequately irrigated hot semiarid to hot sub-humid regions of the Indus and Gangetic alluvial plains (21^{0}32’24” to 33^{0}07’48” N latitude and 67^{0}04’48” to 90^{0}58’40” E longitude) of India, Bangladesh, Nepal and Pakistan. In India alone, IGP occupies 65 m ha covering the states of Punjab, Haryana, Uttar Pradesh, *Tarai* of Uttaranchal, Bihar and West Bengal which is about 20 per cent of the geographical area of the country (21^{o}31’ to 32^{o}20’ N latitude and 73^{o}16’ to 89^{o}52’ E longitude). The annual rainfall ranges from less than 400 mm in the northwest to more than 1800 mm in the lower Gangetic plains of West Bengal and Bangladesh (Figure 2). Nearly 85 % of the total precipitation is received during the monsoon season between June and September. During winter months a few showers are received between December and February due to western disturbances. Weather is cool and dry in early part of wheat growing season (November to February) whereas temperature rises during grain filling period (March-April), more pronounce in eastern part of IGP, resulting reduced length of wheat growing period. On the other hand, warm humid monsoon season prevails during rice growing period (June to September). In the eastern part of IGP (Bihar, terai of Nepal, West Bengal and Bangladesh), rice can be grown in three seasons viz. *Aus* (April to July) *Aman* (July to

Figure 1: Transect map based on agro-ecological zones of Indo-Gangetic Plains

Source: RWC, New Delhi, India

Figure 2: Rainfall pattern scenario for Indo-Gangetic Plains

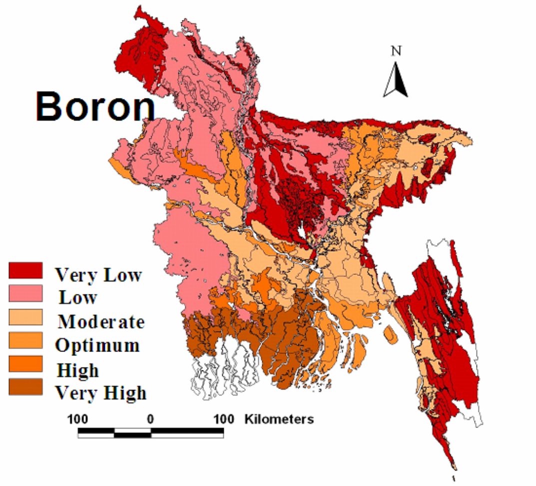
Source: RWC, New Delhi, India



November) and *Boro* (November to April). Temperatures are higher in the eastern IGP reducing the length of growing period of wheat.

Whereas Gangetic plains gradually slope from northwest towards the Bay of Bengal, soils in the Indus plains slope towards the Arabian Sea. There are wide variations in soil types, generally coarser (sandy loams) in the upper Gangetic plains and becoming finer with the run of the river systems. Soils are primarily calcareous, micaceous alluviums from fine sandy loam to loam in texture in the upper reaches becoming finer textured (fine sandy loam to silty clay loam) in the distal plains close to the mouth of the river systems. Irrigated and rainfed agriculture co-exist in most areas leading to a mosaic pattern of agricultural development. Most soils in the IGP are deficient in nitrogen and phosphorus is next in order. Because of micaceous nature of the soils, farmers have avoided the use of potassic fertilizers for a long period. Iron and zinc deficiency are commonly seen in many parts of the IGP. In eastern parts deficiency of boron is also prominent particularly in slightly acidic soils (Figure 3). Many farmers who grow modern cultivars have reported sterility in wheat and cauliflower.

Figure 3: Status of zinc in lower transect of IGP (Region 5)



Source: Bangladesh Country Almanac

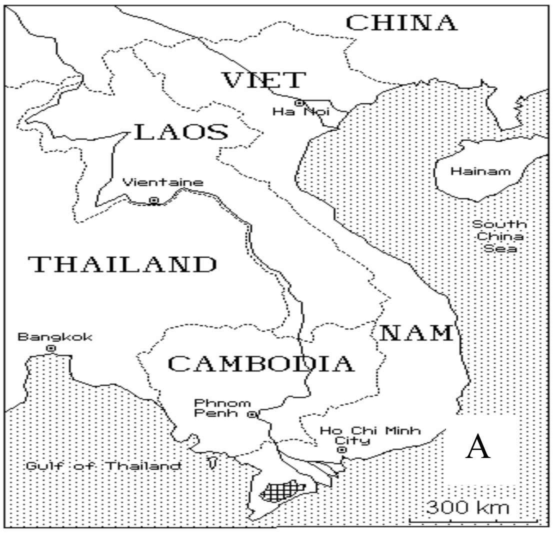
Traditionally, coarse cereals such as barley, millets, and Indian mustard, chickpea and wheat were grown in the Trans-upper Gangetic plains and wheat, rice and sugarcane crops were grown in irrigated middle plains. Wet-land crops such as rice and jute occupied the terminal portion of the lower IGP. Agriculture was subsistence, by and large monsoon dependent and risk prone. Rice-wheat systems represent 32 per cent of the total rice area and 42 per cent of the wheat area in India, Nepal, Bangladesh and Pakistan (Hobbs and Morris, 1996 and Ladha et al., 2000). In India, IGP occupies nearly 20% geographical area of the country to produce nearly 50% the total food grains and hold nearly 40% of the total population of the country.

1.2. Sloping Lands in Vietnam

The total geographical area of Vietnam is 33.091 m.ha of which only 7.384 m.ha (~ 22%) are suitable for agricultural production (Figure 4). Per capita agricultural lands have reduced from 1,318 m^2 in 1980 to 914 m^2 in 2003 due to increase in population pressure. Vietnamese economy is based on agriculture. Nearly 75% of the populations, living in rural areas, depend on agriculture for their livelihoods. High population pressure reduced the forest cover from 14.3 million hectares (43%) in 1945 to 9.3 million hectares (28%) in 1993. However, with efforts of the local government and international organizations, it has now increased to 36.5% (Department of Forest Development, after Vu Tien Hinh, 2003). It is a remarkable achievement for the Vietnamese people that the country, with just 7.4 m ha land under cultivation has emerged as the third largest rice exporter in the world. In addition, it is one of the world leading exporters of aquaculture products, coffee, tea, cashew nut and rubber.

Vietnam has a mosaic pattern of agro-climate and social environments. Sloping lands, with less than 15^o degree slope occupy 21.9% of uplands in the hills. Lands with $15\text{-}25^o$ degree slopes occupy 16.4% area and > 25^o slope account for 61.7 area in mountain sides. Thus, most lands (78%) have more than 15^o degree slopes. Many of the highly sloppy lands are also used for agriculture causing wide spread erosion associated problems. Many sloping lands (>15^o degree slope) are going out of cultivation for urbanization, roads and construction of reservoirs. Therefore, lowlands in valley portions serve for the main source for production for both the present and future generations.

Sloping lands are highly vulnerable to soil erosion especially in locations with higher slopes. Unfortunately, lots of people depend on sloping lands for food and housing. Sloping lands become highly vulnerable to degradation and erosion if not handled properly. Technological solutions to the problems of producing more food on a sustainable basis on sloping lands are labour intensive and tough to implement. Farmers often adapt these technologies with modifications to suite their socio-economic environments. The major efforts in the region should be towards developing the economy of mountainous farmers so as enable to enable them to preserve natural resources and avoid environmental degradation. Field trials do suggest that by using eco-friendly technologies, it is possible to get high and stable crop yields, enhance soil fertility and preserve ecosystems of sloping lands.



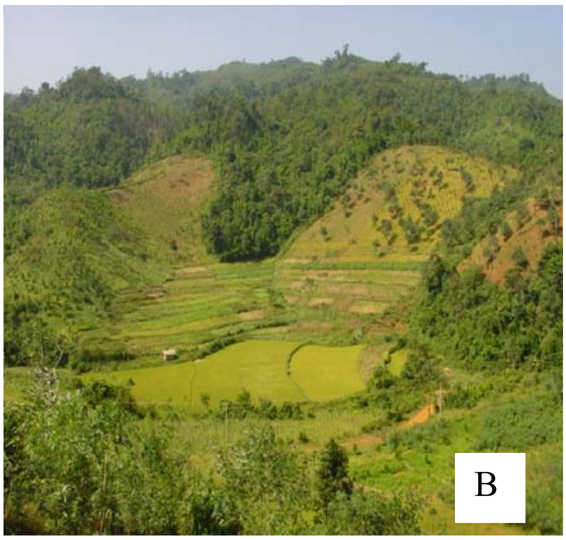


Figure4: General map of Vietnam (a) and the picture showing complex landscape comprising of the steep and gently slopping lands (narrow and wide terraced and un-terraced lands) and flat lands in the valley portion(B). (Source of Photo: SAM 1-Cropping Systems: VASI/CIRAD)

In the past, many experiments had been conducted in Cho Don district of Bac Kan province of North Vietnam wherein different types of mulch practices such as (i) dead mulch (crop residues), living mulch (Green manures, cover crops) , in-situ mulch(Brachiaria and Mucuna grown in main fields 2-3 months before growing season of rice and maize in uplands and knocked down before sowing of the cereal crops), imported mulch, mini-terraces with surface cover (mulch), soil cooking and subsequent mulching, etc.

Soil cooking is followed in landscapes where it is not possible to rehabilitate highly degraded lands. For soil cooking trenches, variable in length, 30 cm and deep are opened and filled with dry crop residues and rice husk. After filling the trenches with residues, they are covered with a 10cm thick layer of soil. At regular intervals (1-1.5m) open vents are provided to facilitate burning of the residues in the trench (Figure 5).

Figure5: Soil cooking for improvement of degraded lands in Vietnam.*(Source:SAM-1, 2001)*

Rice crop is planted on both sides of the trench after mulching of the cooked soil. Siliceous materials from rice husks and straws manipulate the electrochemical properties of the soils in a manner that helps reduce liming requirement and P fixing capacities of the acidic soils. The practice is however still highly localized and being experimented by few farmers. It seems that rice straw mulches retained on the soil surface can possibly have the same effect as of soil cooking on P fixation. Longer term experiments however need to examine such benefits of siliceous materials on crop production in acidic soils.

2. Description of cropping systems and driving forces

2.1. Rice-wheat cropping system in IGP

Land use pattern in the Indo-Gangetic Plains region has undergone spectacular changes to ensure national food safety for the growing population and increasing per capita food availability which was the burning challenge during the last four decades. The key elements of the strategies adopted for reversing the past trends included the genetic improvements of high yielding input responsive varieties and their adoption, expansion of irrigation system, expansion in area of arable lands, investments in agricultural research and development, infrastructure development including electrification, credit facilities and amplified use of agronomic inputs like inorganic fertilizers and pesticides. Being endowed with well developed groundwater aquifers irrigation expansion by development of groundwater mainly through private tubewells in the northwest IGP has been particularly amazing. Increased availability of water on the farm, technological breakthrough leading to development of short duration and short stature plant types responsive to high inputs, particularly of rice and wheat, led to steady expansion in cultivated area and crop productivity. Rice-Wheat cropping system (RWCS) in which farmers raise rice and wheat crops in a sequence on the same field has emerged as a major cropping system of the region in the last three decades.

Demand for rice and wheat is expected to grow at 2.5 % per year over the next two decades but it will become increasingly more difficult as the per capita rice–wheat growing area has already shrunk from 1200 m^2 in 1961 to less than 700 m^2 in 2001 (Singh *et al.* 2002). The climate of the IGP has been also favorable for rice and wheat to be grown in a double cropping pattern within one calendar year, rice in the summer and wheat in the winter. The cropping patterns are numerous and varied, with at least two and sometimes three or more crops grown in any one calendar year

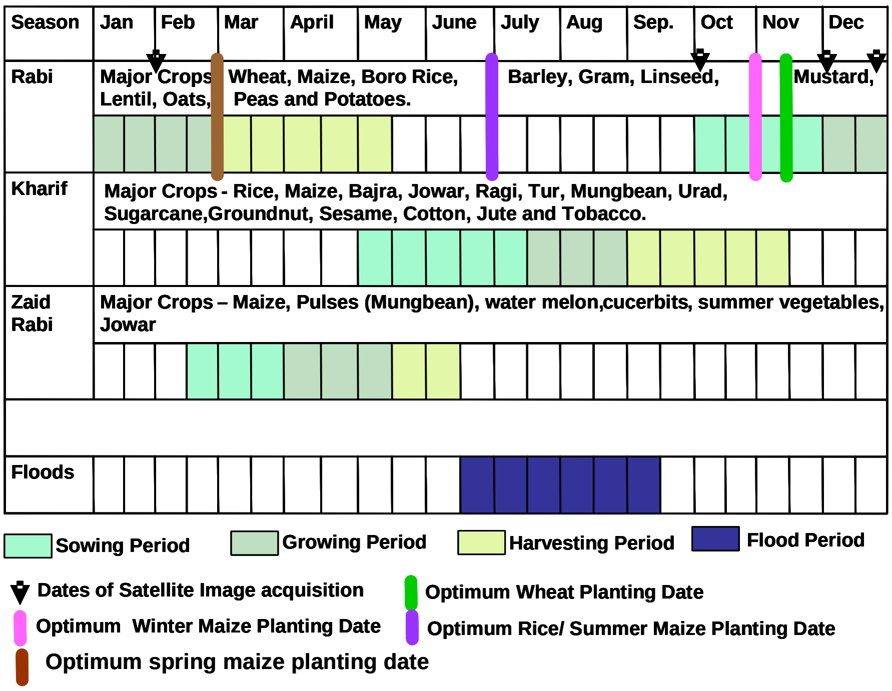


Figure 6: Crop Calendar for Indo -Gangetic Plains

(Figure 6). The triple and more intensive cropping patterns are found in middle and lower IGP, where temperatures average relatively more than in the Trans and upper IGP. There are many fields where farmers grow continuous rice–wheat, but in many cases, rotations break this continuous cereal system. Sugarcane, for example, is used in rotation with rice and wheat in parts of the IGP where it occupies the land for two or more years before returning to rice and wheat. The characteristics feature of different transects of Indo-Gangetic Plains has been summarized in (Table 1)

Table 1. Characteristics driving forces for Agricultural development in the IGP transects

Characters	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
Geographical area	Trans Gangetic plains in Pakistan Punjab	Trans-Gangetic plains in Punjab, HP and Haryana, India	Parts of Haryana, western and central UP, Terai of India and Nepal	Eastern UP and parts of Bihar and eastern parts of Nepal	West Bengal and Bangladesh
Cropping systems	Intensively irrigated Rice-wheat systems. Mostly basmati rice types	Rice-Wheat-Maize+Cowpea(f); Rice-Wheat-Cowpea(f) Rice-Wheat-Green-Manure Rice-Potato-Wheat Rice-Wheat-Mungbean Rice-sugarcane-Ratoon- rice-wheat Rice-Wheat-Sunflower	Rice-sugarcane-Ratoon- rice-wheat ; Maize-Wheat P.pea –gram /wheat Soybean-Wheat Soybean-Wheat-Gram Maize + Potato-Wheat Cotton - Wheat	Rice-Potato-Wheat/ Sunflower Rice-Jute Rice-Wheat-Rice Rice-Potato-Maize Rice- Rice Rice-Potato- (*Boro*) Rice-potato-Onion Rice-lentil-Onion	Rice-Jute Rice-Potato-Rice (*Boro*) Rice-potato-Onion Rice-rice (*Boro*)
Biophysical drivers of Agricultural development					
Climate	Semiarid with 400-800 mm annual rainfall, 85% received between June to September	Semiarid with 400-800 mm annual rainfall, 85% received between June to September	Hot sub-humid, annual rainfall up to 1000 mm, of which 75-78% received in monsoon season.	Hot sub-humid, annual rainfall up to 1800 mm of which 75-78% received in monsoon season	Hot sub-humid, annual rainfall up to 1800 mm of which 70-78 % received in monsoon season
Physical features	Alluvial coarser to medium fine textured calcareous soils, gently sloping, good drainage, alkali soils also exists in stretches. Ground water quality low in pockets, Marginal lands being reclaimed.	Alluvial coarser to medium fine textured calcareous soils, gently sloping, saucer shaped topography; alkali soils also exists in stretches; water quality low in pockets. Marginal lands being reclaimed.	Alluvial coarser to medium fine textured calcareous soils, gently sloping; acidic soils in hills; alkali soils also exist in stretches, water quality low in pockets. Marginal lands being reclaimed. Changing river courses affect farming and livelihood conditions	Alluvial medium fine textured calcareous & acidic soils, gently sloping, low-lying, flood prone; drainage congestion, ground water quality low in pockets due to fluorides and arsenic. Changing river courses affect farming and livelihood conditions.	Alluvial soils, medium fine textured calcareous & acidic soils, gently sloping, low-lying, flood prone; drainage congestion, ground water quality low due to fluorides and arsenic. Holdings fragmented and relatively small sized. Farms highly diversified and

					flood prone.
Irrigation	Long distance inter-basin transfer of water, intensely irrigated systems, extensive ground water development, use of low quality ground waters for irrigation	Long distance inter-basin transfer of water, intensely irrigated systems, extensive ground water development, use of low quality ground waters for irrigation	Long distance inter-basin transfer of water, intensely irrigated systems, extensive ground water development. Some use of low quality ground waters for irrigation	Irrigated agriculture mainly in winter season, less ground water development, life saving irrigation in monsoon season or as flood management measure.	Irrigated agriculture mainly in winter season; life saving irrigation in monsoon season, intensive ground water development.
Energy and power	Tractorization very popular, rice being mechanized	Tractorization very popular, rice being mechanized	Tractorization very popular, rice being mechanized	Tractorization less popular, depends on animal power.	Small tractor very popular, also depend on animal power
Research Backstoppin g	Premier institutional network exist	Premier institutional network exist	Institutional network exist and relatively good	Research backstopping relatively inadequate	Premier institutional network exist
Bio-climate	Favorable to RWCS, Cereal based systems;	Favorable to RWCS; Cereal based systems	Favorable to RWCS; Cereal based systems with sugarcane	Favorable to Rice based systems, highly diversified	Favorable to Rice based systems; highly diversified
Socioeconomic drivers					
Farmer education & drive	Middle level and highly enterprising with capacity to take risks. Affluent farmers. Agricultural holdings consolidated but relatively medium sized. Enhanced growth of peri-urban agriculture	Middle level and highly enterprising with capacity to take risks; Affluent farmers. Agricultural holdings consolidated but relatively medium sized. Enhanced growth of peri-urban agriculture and private sector agro-industries.	Middle level, enterprising with capacity to take risks; Affluent to poor farmers. Agricultural holdings consolidated but relatively medium sized. Enhanced growth of peri-urban agriculture and private sector agro-industries.	Primary level and enterprising with less capacity to take risks; farmers generally poor and more risk prone. Agricultural holdings fragmented but relatively small sized. Farms highly diversified. Private sector agro-industries less conspicuous.	Middle level and enterprising with less capacity to take risks; farmers generally poor and more risk prone. Agricultural holdings fragmented but relatively small sized. Farms highly diversified. Private sector agro-industries less conspicuous.
Infrastructural support for inputs; technology & extension	Very good	Excellent support	Good infrastructure with relatively less extension support	Poor infrastructure with relatively little extension support	Good infrastructure with good extension support
Marketing of produce	Favorable to rice and wheat	More favorable to rice and wheat	More favorable to rice and wheat	More favorable to rice and	More favorable to rice and wheat

				wheat	
Policy support	Adequate	Adequate	Relatively less adequate	Less than adequate	Adequate

The rice and wheat crops contributed a major part in the total food grains production as rice-wheat cropping system is one of the most important cropping patterns for food safety in the region. This system in IGP has been favoured by a number of biophysical and socio-economic driving forces. The major biophysical forces which promoted the rice-wheat cropping system in IGP include climatic suitability, soil types, and water availability. The climate of the IGP is sub-humid with a distinct wet monsoon summer season and a dry cool winter season. This allows rice and wheat to be grown in a double cropping pattern in one calendar year, rice in the summer and wheat in the winter. Soils are mainly alluvial in nature as a result of the deposition of the Indus and Ganges river systems. Soils range in texture from loamy sands to silty clay loams and are probably one of the most fertile and productive agricultural areas of the world. Though some problematic soils (alkaline/acidic in pH) are also present in the region. The IGP are gifted with extensive canal irrigation systems using water storage reservoirs in the Himalayan mid-hills. Canal irrigation is supplemented with tubewell water and most rice-wheat areas are irrigated or partially irrigated. The other factors that enhance the rice-wheat cropping system in IGP includes the suitability of different resource conserving technologies (zero/reduce tillage, direct seeding, bed planting, laser levelling, green manuring, crop residue management etc.) to this system.

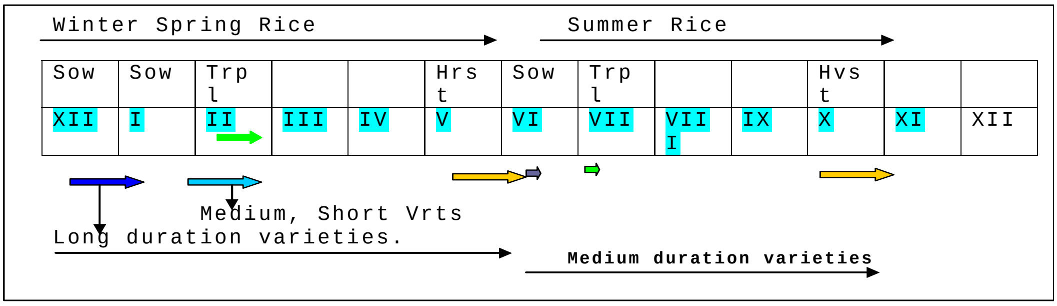
2.2. Rice and Maize based production systems in mountainous regions of Vietnam

Cropping patterns in Vietnam vary widely between lowland and upland, between the South with typically tropical and the North with sub-tropical climates, and of course between different sub-ecological regions. For example, in the South of Vietnam, because of high temperature regime year round, farmers can grow even 3 rice crops per year. The big problem there is to arrange suitable cropping seasons to avoid flooding damage. In the North, however, three rice crops/year is almost impossible because of cold winter, but farmers can grow other winter crops. In mountainous regions, the cropping patterns are still more diverse. Some typical cropping patterns/systems are described as follows:

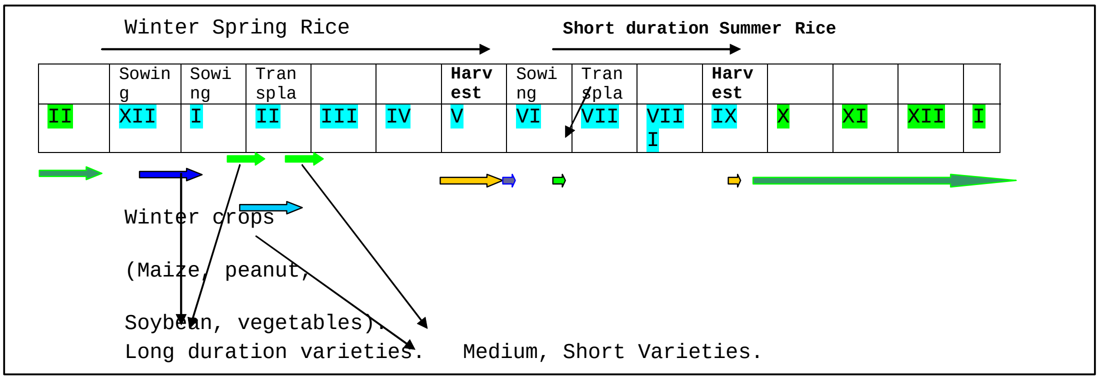
2.2.1. Irrigated rice-based crop calendar in North Vietnam (valley portions)

Two major cropping systems are followed in irrigated lowland areas of North Vietnam, namely (i) Rice-Rice; and (ii) Rice–Rice–Winter crops. Rice is generally grown as puddled transplanted rice. The cropping intensity in irrigated systems is very high. In rice-rice lowland system is plateauing yields is a major concern which can be overcome through improved germplasm (for yield, grain quality, biotic/abiotic resistance) and adoption integrated crop management practices. Puddling destroys soil structure, transplanting involves drudgery. A key issue with the rice production system is how we can reconcile the current crop establishment and management practices with elements of Conservation Agriculture. Direct dry seeding of rice and co-culturing techniques of rice with GM crops could bridge the missing links of rice culture with CA. How to do this without yield penalty is a question yet to be answered with fairly high degree of confidence.

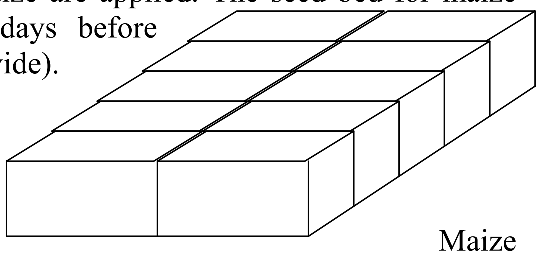
a) Rice-Rice (two rice crop seasons) in lowland Valleys

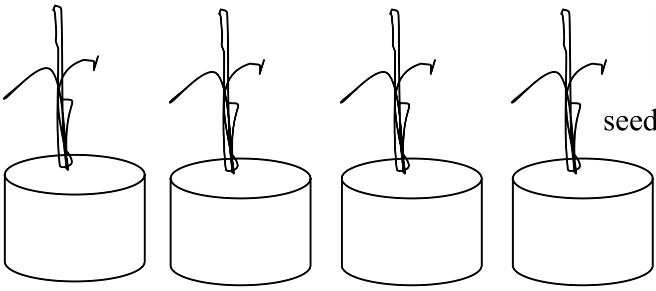


b) Rice (medium short) -rice (short duration) –soybean/maize/peanut/vegetable (For two rice seasons and one winter season) (irrigated low lands in the valleys)



In case the summer rice cannot be harvested before 15 September, relay cropping for soybean, and pot-sowing-then-transplanting for maize are applied. The seed bed for maize seedlings made of mud on plat space 15-20 days before harvesting rice (each pot is 5-7 cm thick, 4 x 4 cm wide).





Maize seedlings at 12-15 day age that are ready for transplanting in to newly harvested rice fields by mini-tillage of soil.

c) **Single rice season in summer in the valleys and terraces** ***(No water or uncertain water supply in spring season)***. The rice crop grown during the period between May to Novemebr is generally irrigated but could in some places be even rainfed. After harvest of the rice crops farmers generally opt for winter crops with residual soil moisture. . The productivity of the second crop is invariably low due to moisture shortages. Techniques such as para-cropping or relay ceopping in no-till situation and residue management can enhance water supplies and hence productivity.

Long, medium, short duration rice varieties.

						Sow	Trplant			Hvst	Hvst			
II	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I

Winter wheat, vegetables, legumes, fodders
Winter crops

d) Upland Rice based systems sloppy lands (variable slopes)

Long, medium, short duration rice varieties.

						D. Sow	D. Sow			Hvst	Hvst	Hvst		
II	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I

Vegetables, legumes, fodders

Winter wheat, vegetables, etc.

Good time for fodder and mulch production.

On the sloppy lands, there is a paucity of water, so only rice crop is grown during the monsoon season (May–Oct/Nov). Near the homesteads, some farmers grow vegetables, fodder and pulses just for meeting their family needs. After a single rice crop, land is often left fallow for animal grazing. There seems to be an opportunity to grow a second crop as para crop (winter wheat, fodder, pulse crops) in the residual moisture of the preceding rice crop using surface seeding/no-till agriculture.

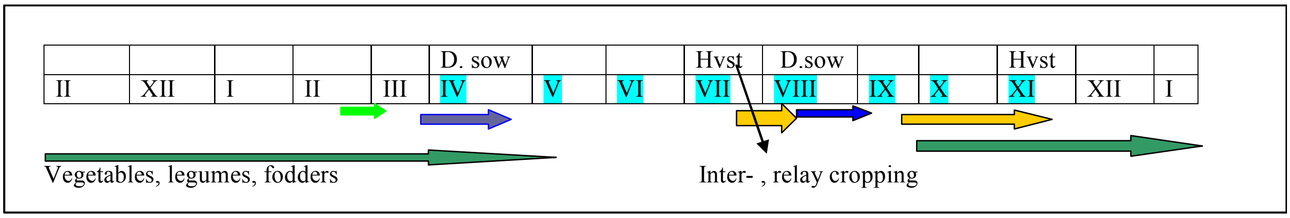
Rice is generally grown in lowlands as puddled transplanted crop. This requires lot of irrigation water in puddling. However in uplands, commonly farmer manually dibble a mix of short and long duration rice cultivars after the first monsoon rains. They generally establish 20-30 hills /m2. Some farmers establish rice by broadcasting rice seed at the rate 100kg/ha and then do light tillage (harrowing) to cover the seeds drawn by animals or just manually. Normally, such farmers do not apply any fertilizers and depend on inherent soil fertility. Do manual weeding and use no herbicides for weed management. Therefore, yield of direct seeded rice invariably depend on soil fertility , rainfall patterns, sloppiness, and cultivar choices. In initial years, rice productivity is around 2-3 t/ha but declines fast due to soil erosion, declining soil fertility and weed infestation , may be 15-20 percent per year.

In order to improve the productivity of this system, VASI has introduced the elements of Conservation agriculture such as residue management and agro-forestry practices. It appears that it is possible to improve and stabilize the productivity of the DSR rice crops on

sloppy lands by reducing the seed rate, provide soil by brown manuring and use of mulches rich in phosphorus and potassium (Figure 7).

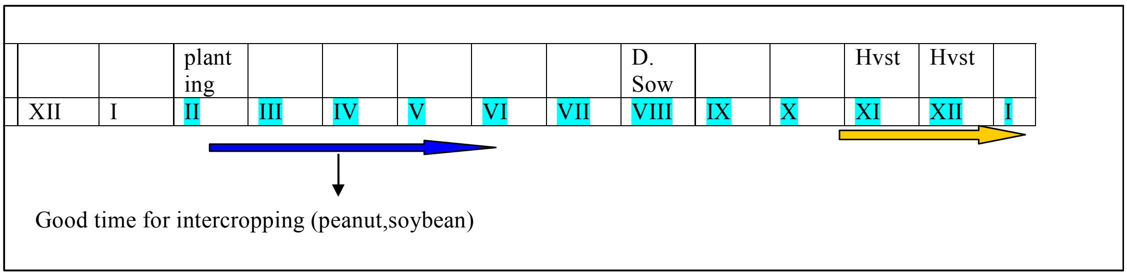
Figure 7: Useful plant species [A- *Chromoleana odorata* -rich in K and *Tithonia diversifolia*-rich in P] for nutrient management.

e) Two maize season systems: Maize-Maize system



On other sloppy lands mostly in northwest Vietnam because of market availability farmers go for double maize cropping (cobs, grains, fodder) maize crop is grown during the monsoon season (April–July and again from July-Oct/Nov) There seems to be an opportunity to intercrop maize with soybean, cowpea, *Brassica* (during second maize crop using surface seeding/ no till agriculture. There is a need to diversify the mono-crop as double maize cropping system as the winter maize suffers from water shortages in the slopping lands. Surface cover and no-till agriculture has great potential for improving the productivity of the second crops such as winter wheat, legumes or even of winter maize.

f) Cassava based systems



In recent times, cassava cultivation has become more popular with the farmers as it gives more profit. But the cassava cultivation leads to more soil erosion. If Cassava is intercropped with peanut/soybean, it helps to reduce soil loss and improves profitability (Table 2). There a number of plant species can be intercropped with cassava as live mulch to reduce the soil loses through erosion (Table 3).

Table 2. Results of cassava intercropping in Tran Phu – Chuong My – Ha Tay

(Source : Trinh Phuong Loan et al, 2002).

Treatments	Cassava yield (t/ha)	Yield of associated crop (t/ha)	Total income (USD/ha)	Balance (US$/ha)

Control: Cassava only	29.5	-	550	496.3
Cassava with 1 row of peanut	22.4	1.0	723.8	670.0
Cassava with 2 rows of peanut	32.0	2.1	1262.5	1208.8
Cassava with mungbean	33. 5	0.4	825.0	771.3
Cassava with water melon	32.1	-	601.3	547.5

Table 3: Effects of hedgerows on soil erosion and yield of cassava in Hong Tien–Son Duong–Tuyen Quang (Nguyen The Dang et al., 2002).

Treatment	Eroded soil (t/ha)	Cassava yield (t /ha)
Control	106.0	26.3
Cassava + Tephrosia bands	15.0	28.7
Cassava + Vetiver grass bands	7.1	27.0
Cassava + Paspalum atratum bands	7.2	31.2
Cassava + Panicum maximum	6.2	27.0

2.2.2. Agro-forestry systems on steep slopes

Agro-forestry is generally practiced on sloppy lands, particularly the steeper landscapes with more than 15^o slopes. Farmers generally intercrop maize, and other annual crops including rice with woody tree species such as *Chucrasia tabularis.* Agro-forestry systems on sloppy lands could be more effective for increasing the crop productivity. A number of plant species are available in Vietnam which fix atmospheric nitrogen and also provide very good live mulch to protect the soil from erosion. As shown in Table 4, maize is co-cultured with various live much as under story of *Chucrasia tabularis.* Results show that making mini-terraces in second year (2002) dramatically improved maize productivity. Mulching further enhanced the maize productivity. A*rachis pintoi* was found as the more effective live mulch amongst the all those tested.

Table 4: Increasing trend of maize yield intercropped under *Chucrasia tabularis* in mini-terraced fields having > 25^o slopes (VN, SAM 2002)

Live mulch plants (Inter crops with Maize)	Yields (T/ha)	
	2001 (No terrace)	2002 (Terrace)
Maize + Cassia rotundifolia	1.44	2.39
Maize + Arachis pintoi	1.77	4.01
Maize + Brachiaria ruziziensis (Cuttings from outside)	1.35	2.83

Maize+ B. riziziensis (seeded in 2000, killed in 2001)	1.59	2.11
Maize + A. pintoi	1.18	4.17
Maize + weeding (no mulch)	1.07	3.77*

* in year 2002, the plots were mulched and no weeding was done

2.3. Why rice based systems are important to IGP and Vietnam?

Presently RWCS are practiced on nearly 13.5 million ha (10.0 m ha in India, 2.2 m ha in Pakistan, 0.8 m ha in Bangladesh, and 0.5 m ha in Nepal) in the Indo-Gangetic plains (Ladha *et al.* 2000, Gupta *et al.* 2003; Hobbs and Morris, 1998; Woodhead *et al.* 1993; 1994; Zheng, 2000; Timsina and Connor. 2001; Razzaque, *et al.* 1995; Lianzheng and Yixian, 1994; Huke et al. 1993 a, b, c). Data in Table 5 indicate that total contribution of rice and wheat crops to total cereal production in South Asia is more than 80%.

Table 5. Area of rice-wheat systems, their contribution to rice-wheat system area and to total cereal production in various Asian countries.

Country	Rice-wheat area		Area contribution (%) of the system-crop to the total area of individual crop				Contribution of rice and wheat to total cereal production‡	Contribution of rice-wheat systems to total rice and wheat production†
			Rice		Wheat			
	Estimate 1†	Estimate 2‡	Estimate 1	Estimate 2	Estimate 1	Estimate 2		
	--------Mha--------		--%--					
China	-	13.5	-	31	-	35	72	-
India	9.1	10.3	22.3	23	38.7	40	85	25.7
Pakistan	1.6	2.2	80.3	72	22.4	19	92	35.8
Bangladesh	0.5	0.5	4.9	5	84.7	85	100	7.9
Nepal	0.6	0.6	34.3	35	81.7	84	71	77.6

Adapted by Gupta et al. (2003) data used from †, Hobbs and Morris (1998). ‡, Timsina and Connor (2001).

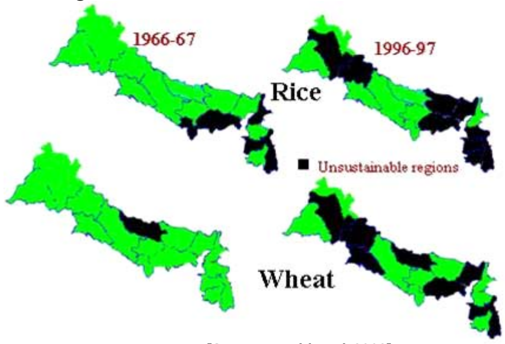
Rice and wheat are the world's two most important cereal crops, contributing 45% of the digestible energy and 30% of total protein in the human diet, as well as a substantial contribution to feeding livestock (Evans, 1993). Rice and wheat are the major food crops of the Inod-Gangetic Plains region. It has been reported that contribution of only these two cereals resulted a quantum gains in foodgrain production. During last four decades the growth rates of rice and wheat production in South Asia (2.5% and 5.2% per year, respectively) exceeded the population growth rate (2.22% per year), indicating an increase in the per capita availability of these two cereals that strengthen the food security, reduced rural poverty, and increased affordability of food at cheaper prices in the region (Pingali, 2001). Demand for rice and wheat is expected to grow at 2.5 % per year over the next two decades to feed the future generations. Inevitably, this encouraged large-scale sequential cropping of rice and wheat in millions of ha even in non-traditional areas for both crops. The most of quality rice (Basmati) produced in the IGP for export and generate the foreign exchange and enhancing the farmer's economic standard. The cropping system of any region has been governed by the major food habit of the peoples, profit margins and minimum risk. Rice and wheat are the first choice of the farmers in IGP because the major cereals in the northwest (Transect 1 & 2) and eastern (region 3-5) IGP are wheat and rice, respectively which boost the cultivation of rice and wheat in the IGP. Rice- wheat cropping system is the most economic system in terms of net return to the farmer's of IGP as compared to any other cropping system practiced in the region that makes this system most popular.

The total geographical area of the Vietnam is 33.091 m.ha from which, about 28 per cent area is suitable for agricultural production and exists at variable elevation and slopping. The per capita agricultural lands have reduced from 1,318 m^2 in 1980 to 914 m^2 in 2003 due to tremendous increase in population. It necessitates the greater productivity from per unit area to feed the growing population. Rice and Maize are the most important crops in the Vietnam. Rice based cropping systems in Vietnam became more important with the introduction of newly improved rice varieties (San uu 63, Khang dan, Lun 32 etc.), having high productivity potentials. The rice area in Vietnam accounts for 7.449 m. ha that produced 34.519 m.tons with an average productivity of 4.64 t/ha during 2003, while the area under maize is about 0.91 m. ha with a total production of 2.935 m.tons, and an average yield of 3.23 t/ha (FAO, 2004). Rice is a staple food crop for human whiles the maize has great importance for human food and animal feeding as well. The diverse climatic conditions facilitate the rice and maze based cropping systems with variable cropping intensity between lowland and upland, in the South (typically tropical) and the North (sub-tropical climates), and of course in different sub-ecological regions. Farmers can grow even three rice crops per year due to high temperature regime around the year and greater rainfall in the South part of the country. The export of rice from Vietnam also make rice based systems of great importance as it reached to 3.241 m.tons in the year 2002 that secured a sum of $726 million foreign exchange to the country (Source: Vietnam Panorama Online News). At the slopping land the major problem is loss of fertile soil with runoff water as soil erosion. The rice and maize based cropping systems produces huge amount of residues that is very useful as mulch at the slopping land to conserve the soil moisture and check the soil erosion (Tuan *et al.*, 2003).

2.4. What ails RWCS in the IGP?

Although production problems are unique to each transect of the IGP, the description of complex inter-related factors like delayed transplanting of rice, excessive tillage, weed infestations and soil wetness delay planting of winter season crops with resultant low crop productivity in the R-W systems. Herbicide resistance and problems with lowering water tables were major factors for unsustainability of R-W system in northwest IGP (Malik *et al.*, 1998). Added concerns of residue management, organic matter decline, low input use efficiency, water-table declines, salt build-up, soil biota, reduced biodiversity and environmental quality only suggest that rice-wheat systems are unsustainable (Ladha *et al.* 2003, Joshi et al,

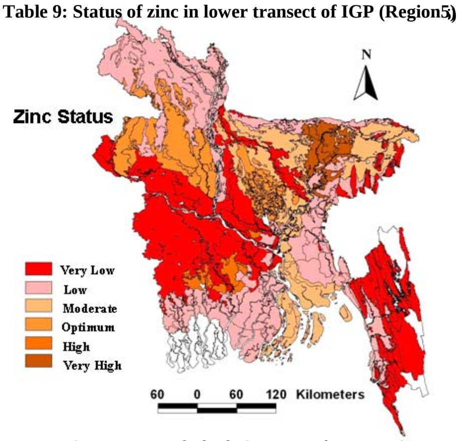
Figure 8: Change in sustainability scenario of Rice and Wheat in IGP during last three decades.



[Source: Joshi *et al*, 2003]

2002) in their present form in many areas (Figure 8). Rice-wheat monocropping in IGP has been showing signs of exhaustion and concerns are now being expressed about the sustainability of rice-wheat systems (Hobbs and Morris 1996). Continuous cultivation of rice and wheat is lowering soil fertility and organic matter (Yadav *et al.* 1998), depleting ground water resources in tube-well irrigated areas (Gulati 1999), exacerbating weed and herbicide resistance in weeds (Malik, 1996), disease and pest problems (Pingali and Gerpacio 1997). Even micro-nutrient deficiencies started appearing in the IGP with the adoption and spread of intensive agriculture (Nayyar *et al.*, 2001). Among other factors, zinc deficiency has become most widespread in the entire IGP region especially in region 5 of Lower IGP (Figure 9). The biophysical and socioeconomic heterogeneity in different IGP transects must be borne in mind in any analysis for future planning. In the northwest, essentially a wheat-based production system, introduction of intensive rice cultivation has raised concern about environmental sustainability due to antagonism between the current soil-water production requirements of the two crops. Sustainability of the production system is threatened by over-exploitation of ground water and inappropriate water-management practices, especially in the western transect. Canal water accounts for 35-40% of the total irrigation requirement and the remaining is met from groundwater. This has resulted in decline in the water tables and water quality in many regions (Sinha *et al.*, 1998). Excessive groundwater exploitation from fresh water aquifer zones has led to decline in water-table, and to rise in water-table in areas with low quality aquifers. The rate of fall of water table in Yamuna basin and district Ghaziabad of India has been 0.5 m and 0.9 m per year, respectively (Srivastava 1998). In Pakistan during rice-wheat season over-pumping has resulted in ground water decline ranging from 27 to 76 cm in several water courses (PARC-RWC 2003). Low quality aquifers having problems of residual alkalinity, high sodium adsorption ratio and or excess salts are found in substantial areas of the IGP (Figure 10). It is estimated that nearly one-third of the total irrigation water demands of crops are met through use of low quality ground waters (Gupta et al., 1994). It has observed that compared to canal irrigation, crop yields are higher in areas irrigated by tube-wells mainly because of timely watering of crops. The IGP is endowed with rich water resources from monsoon rains and snowmelt-fed rivers and canals. The over-utilization of low quality groundwater and the seepage for vast canal network has, however, led to water logging and soil salinity in many parts of the Gangetic plains. It is estimated that more than 7 m.ha lands suffer from salinity problems (Gupta et al., 1994). Another serious problem now emerging is in saline aquifer regions in the western

Table 9: Status of zinc in lower transect of IGP (Region5)



Source: Bangladesh Country Almanac

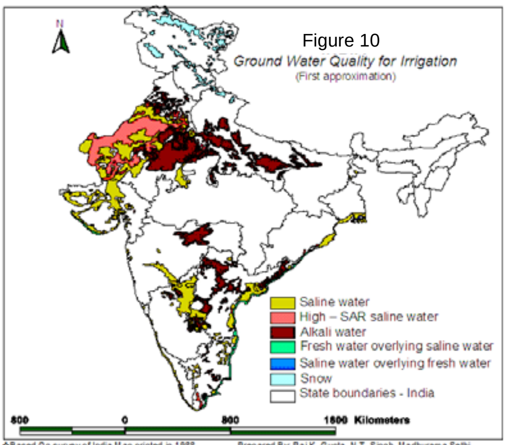


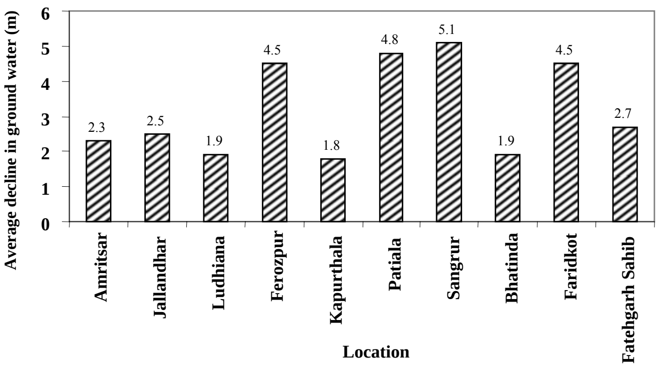
Figure 10 *Ground Water Quality for Irrigation* (First approximation)

❖Based On survey of India Map printed in 1988 Government of India Copyright,1994 — Prepared By: Raj K. Gupta, N.T. Singh, Madhurama Sethi Source: Director, Central Soil Salinity Research Institute Karnal

IGP. For instance, in Pakistan's Sind province, large areas (about 32%) became saline after the introduction of extensive irrigation, compounded by the depth of the water table rising from 20–30 to 1–2 m within 20 years (Pingali and Shah, 1999). In other areas, the massive expansion of private sector tubewell irrigation schemes (as is occurring in Bangladesh, India, and Pakistan) has led to the rapid depletion of ground water. Furthermore, in parts of the eastern IGP (largely West Bengal and Bangladesh) groundwater use is used extensively for *Boro* rice cultivation and also for drinking. It is reported that excessive mining of ground waters has led to build up in arsenic in toxic concentrations in about 45 out of the 64 districts, mostly in the Gangetic flood plains (Islam *et al.*, 1999).

There are many reasons for high usage of ground water including a) zero or negligible tariffs on farm power in some states of India; b) flat tariffs on electric motors is no deterrent for extracting extra water; c) poor quality irrigation system unable to supply water in sufficient volumes on demands for canal water; and d) cultivation of high water requirement crops such as rice and sugarcane in the low rainfall regions. Scenario of ground water depth in various districts of Indian Punjab has been depicted in Figure 11. Results of surveys conducted in Punjab indicate that average annual decline in ground water table is in the range of 1.8-5.1 meters in many districts.

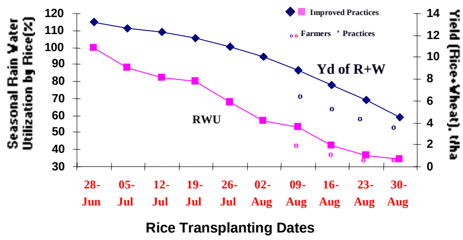
Figure11: Ground water change during 1984-1994 in different districts of Punjab, India. *(Source: Joshi and Tyagi, 1994)*



Whereas, crop production is increasingly becoming dependant on marginal quality land and water resources in the northwest, the eastern parts of the Gangetic plains still rely on surface irrigation and monsoon rains. Most crops suffer from drainage water congestions in eastern Gangetic plains. Even for supplemental irrigation to rice and other crops, farmers are often reluctant to ground water development during monsoon season. For planting winter season crops they develop ground water late in the season. As a consequence, the total cropping system productivity is drastically reduced. Many low-lying areas where rice vacates the fields late in winter season or soils remain excessively wet, farmers are unable to plant a crops leading to 'Rice Fallows'. Such soils occupy more than 4 m.ha in eastern parts of the IGP. With development of some ground water in monsoon season for timely transplanting of rice nurseries and to provide supplemental irrigation to rice and adoption of surface seeding practices in low lying areas, it is possible to reduce acreage of rice fallows. Results of field studies at Patna have indicated that transplanting rice in last week of June not only improves the total productivity of rice-wheat systems but

Figure : 12

Water-Wise strategy for eastern IGP: Advancing the rice transplanting



(Source: Adopted from S R Singh 2000, DWMR)

also improves the efficiency of the rainwater use in eastern Gangetic plains (Figure 12).

It seems to be a rather difficult task to achieve incremental food production in intensively cultivated areas, which are already showing signs of fatigue. Indicative problems of system ecology such as soil organic carbon decline, secondary salinization, greater incidence of multiple micronutrient deficiencies, loss of biodiversity and emergence of herbicide-resistant new weed biotypes are major challenges for sustainability of the rice-wheat systems. This necessitates that productivity gains in intensively cultivated areas are not only secured but further enhanced; and the gray areas made greener to reduce pressure on natural resources in the IGP. Pingali (2001) has concluded that intensive rice-wheat rotation in the IGP results in some specific changes that includes seasonal wet and dry crop cycles over the long term, increased dependence on irrigation and inorganic fertilizers, irregularity in planting schedules and greater uniformity in the varieties cultivated. They also stated that over the long term, these changes impose significant environmental costs due to negative biophysical impacts. The most common environmental consequences of lowland intensification are buildup of salinity and water logging, depletion/contamination of ground water, formation of a hardpan, changes in soil nutrient status, nutrient deficiencies and increased incidence of soil toxicity and increased pest buildup, pest-related yield losses and associated consequences of increased and injudicious pesticide use.

2.5. What ails rice and maize based systems in sloping lands of Vietnam?

Sloping lands are well distributed in Vietnam, but mostly in the Northern mountainous, Central and Tay Nguyen regions. Most of gentle slopes of less than 15^o (accounting for 21.9%) have been used for agricultural and forestry production. The lands with 15^o to 25^o sloping occupy 16.4%. The rest 61.7% are very steep (more than 25%). Acreage of sloping lands with less than 15^o slopes is nearly 21.9% . It is for this reason mountainous farmer has to cultivate lands having steep slopes ($\geq 25^o$) which constitute bulk of sloping lands. On such slopes, runoff rainwater erodes the soils at rates (100-200 t/ha soil loss), not conducive for sustainability of agriculture. It is for reasons of excessive soil erosion; soils with steep slopes ($\geq 25^o$) are often used for cultivation of short cycle crops such as rice and maize usually 2 or 3 seasons before cassava cultivation, a last resort crop. Problems of natural resource management are highly diverse in nature and often closely interlinked with socio-economic conditions of the farmers. Resolution such complex problems call for comprehensive measures. The second major problems relates with non-availability of irrigation water on sloping lands. Rainfed agriculture commonly practiced in Vietnam on sloping lands often have low productivity of the systems The productivities of maize, upland rice and Cassava ranged from 1.5-2.0, 0.8-1.5 and 10-14 t/ha, respectively.

3. What alternatives have been tried in the past in IGP and Vietnam?

Foregoing discussions points out that low productivity of R-W systems of the IGP is associated with late planting of wheat after rice, depletion of ground water and contamination of surface and ground water, over mining of plant nutrients from soil pool, reduction in soil organic carbon, emergence of herbicide resistant weed, pest problems and degradation of soil quality due to salt buildups. A diagnostic study of constraints in rice–wheat cropping systems (RWCs) showed that a high population of *Phalaris minor*, a serious weed of wheat in the RWCs, and a decline in soil productivity were two major constraints of the system (Harrington *et al.*, 1992). Other causes of decline in the Total Factor Productivity of the RWCs throughout the region included declines and changes in soil organic matter, a gradual decline in the supply of soil nutrients causing nutrient (macro and micro) imbalances due to inappropriate fertilizer applications, a scarcity of surface and groundwater, and in some places poor water quality (Paroda *et al.*, 1994). It was noticed that herbicide (e.g., isoproturon) resistance had developed in *Phalaris minor* (Malik and Singh, 1995). Considering these facts related to unsustainability of rice-wheat cropping in Indo-Gangetic Plains a number of alternatives have been worked out. In sloping lands of Vietnam, excessive soil erosion is the prime cause for unsustainability of rice and maize based systems on sloping lands. The main alternatives used for ameliorating the situations thus far have been described in the ensuing sections.

A basket of resource conserving technologies have been developed and made available to farmers for experimentation and adoption. These include zero and reduced tillage, surface seeding, bed planting, real time n management using leaf colour charts (LCC) residue management, paired row planting, single deep placement of fertilisers, precision land levelling etc.. When several layers of RCTs are practiced together, it leads to yield maximization and higher profits. Bed planting systems improves water productivity and promotes diversification of rice-wheat system with high value crops such as vegetables, pulses and oilseed crops. Many of the benefits of no-till wheat are lost during the rice season, traditionally grown as puddled transplanted rice (ploughed while wet). System based technologies are now being promoted that do away with puddling so that total system productivity is raised. Zero-till planting of wheat in residual moisture of rice crop avoids late planting of wheat, saving pre-sowing irrigation and establish the wheat crop early to have smothering effect on weeds (Verma and Srivastava 1994 and 1989). It is estimated that zero till wheat covered an area of more than 2 million hectares in winter 2004, involving several hundred thousand farmers (Figure 13). Zero-till helps reduce carbon emissions (reduced diesel use) and improves input use efficiency while raising system productivity and farm level profits. An exponential adoption rate of zero tillage in different part of IGP was basically a result of farmers' participatory approach (Gill *et al.*, 2000) that not only helps to get timely planting but also improves yields of winter season crops and saves resources, reduces cost of cultivation and population of herbicide resistant weeds. In lower IGP, where the main problem is drainage congestion in monsoon season, adoption of no-till/direct seeding reduces acreage of 'rice fallows' and increases wheat productivity through timely planting. Direct seeding of rice saves energy and water for rice establishment and eliminates drudgery in transplanting. It can result in earlier maturity of rice, which helps fit maize / potato/ Indian-mustard into cropping system. Zero tillage drastically reduces the consumption of fossil fuels, which significantly reduce carbon emissions into the atmosphere and the risk of global warming, and the wear and tear of tractor parts and accessories (Hobbs *et al.*, 2002). Bed planting,

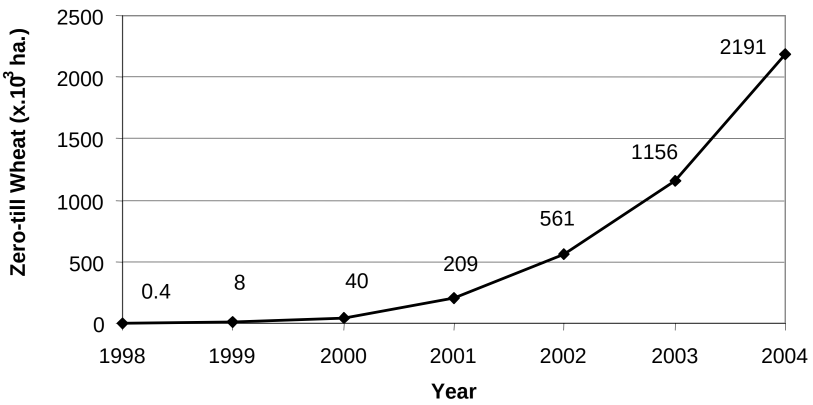


Figure 13 : Changing scenario of zero-till wheat in Indo-Gangetic Plains

especially permanent beds, is gaining acceptance, as more farmers receive equipment to experiment and see the benefits for themselves. Data from India collected at RWC, suggest that use of permanent beds saves even more water (average 31%) than zero-tillage. The practice also improves yields (24%) across an array of crops, increases input-use efficiency, and cuts costs of production (Figure 14).

Zero-till technology is scale neutral and can be used with advantage by all farmers. Timely planting of crops with no-till (zero-till or surface seeding) has many benefits for small farmers: a) lowers production costs, b) improves productivity and c) saves irrigation water and crop residues from burning and d) reduces the acreage of ‘rice-fallows’. The total net gains (excluding the 20-30% saving in irrigation water in wheat) are of the order of US$70-80 per ha in northwest and between US$70-140/ha in eastern IGP. Higher gains are mainly due to yield improvements. It is safe to project that with an estimated area of RCTs at 2.0 Mha, the total benefits accruing to farmers were beyond US$ 140 million in winter season, *2004-05 (RWC-RTCC-2005).* On the basis of field trials conducted across the IGP, it is projected that adoption of RCTs in 2.0 Mha, expectedly would produce at least an additional 0.6 million tons of wheat, besides saving foreign exchange of US$ 80 million through reduced fuel consumption in tillage and irrigation operations, and nearly 2 billion cubic meter of irrigation water

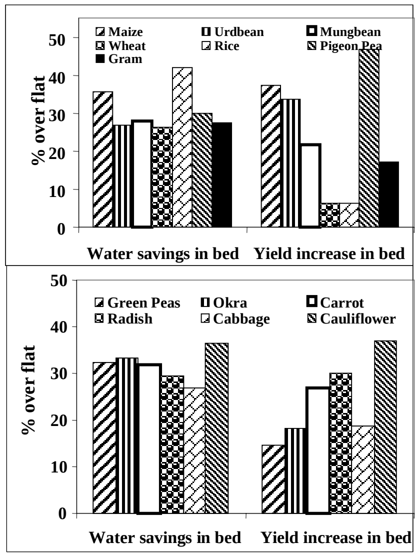


Figure 14 .Superiority of bed planting over flat for yield and water saving for various crops.

3.1. RCTs: A Platform for Reducing ‘Rice Fallows’

In the eastern Gangetic Plains in India, Nepal and Bangladesh, more than 5 Mha remain uncultivated in winter season due to excessive soil moisture after rice harvest (Subbarao etal.200). Such fallow lands are known as; rice-fallows’. Using surface seeding techniques many of these excessively wet ‘rice-fallow’ lands (*Diara, Tal, Chaur* and *Barind* lands) in eastern Gangetic plains can be planted to legumes (lentil, chickpea etc.). By appropriately targeting the resource conserving technologies in eastern IGP, having a mosaic pattern of different ecologies, farmers stand to benefit immensely (Chandna et al. 2004). Timely planting of *Kharif (monsoon season)* and *Rabi* (winter season) crops can additionally produce several hundred thousand tones of food grains, setting in motion a cycle of upliftment of rural poor in eastern IGP and also promote the livestock sector. Farmer participatory field trials have shown that winter maize, potato and *boro rice* has high productivity in eastern IGP. With some ground water development for timely planting, relocating *Boro rice,* traditionally grown in lower landscape positions, to fields vacated by potato, and expanding the acreage of winter maize intercropped with vegetables can change the face of farming communities in eastern IGP (RWC-RTCC-2005).

3.2. RCTs Provides for Alternative sources of Productivity Growth

Although market forces and national policies will drive the pace and form of crop diversification. But an additional factor influencing the diversification of R-W systems would be the new “platform” provided by the resource conserving technologies (RCTs) to resource poor farmers for ameliorating the adverse effects of seasonality in family incomes, peak labor demands, and risks due to monsoonal abrasions. Furrow-irrigated raised bed (FIRB) planting system has opened up new opportunities for replacement of rice with extra short duration pigeon pea (ICPL 88039) and Quality Protein Maize, and for mechanized inter-cropping of sugarcane with (wheat, chickpea, or Indian-mustard) or winter maize with (potato, peas and vegetable crops); and winter wheat with mint. Furrow irrigated raised bed (FIRB) technology is gaining a hold amongst the farmers as this i) saves about 30-40% seed and water, ii) reduces crop lodging, iii) improves grain filling, yield and grain quality, and iv) avoids temporary water logging problems. Resource conserving technologies perform best wherever farmers practice precision laser land leveling. *Laser assisted precision land leveling* increases irrigated area by 2% and cropped area by nearly 3-4 percent besides improving crop stands and yields. Though some ten farmers are already doing custom service with imported laser system, the indigenous prototype developed by scientist of Department of Atomic Energy is yet to hit the market place (RWC-RTCC, 2005).

3.3. Crop Residue management

Residue management is important in rice-wheat systems because large quantities of crop residues are produced, especially where combines are used for harvest or where taller, local, or Basmati rice is grown. Management of these residues has become a major problem for farmers. Many farmers dispose of residues by burning, especially in fields that are combine harvested. Burning can result in up to 80% loss of tissue nitrogen by volatilization (Raison 1979) and can also be a significant source of air pollution. Rice wheat systems produce more than 10 tons of straws. In absence of appropriate planters many farmers used to burn those, wasting precious nutrients and fodder for the animals. Field trials have indicated that one tonne straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2kg SO_2 .(Gupta etal.2004). With development of new prototypes drills that can seed into loose residues, burning of residues can be avoided. Straws retained on the soil surface act as an excellent herbicide, moderate soil temperature and reduce unproductive loss of water through evaporation. To avoid conflict in use of crop residues for surface mulching and for feeding the livestock, co-culturing practices described in a later section have been developed. New dual purpose wheat cultivars which can provide both green fodder and grain with little yield penalty have now become available. Initial indications are that trade-off will still favor integrating wheat research with fodder production for livestock.

An alternative method of straw disposal is needed. Incorporation of straw into soil after harvest is possible in conventional tillage. However, results have shown that incorporation of crop residues leads to a decrease in yield of the next crop because of nitrogen immobilization (Sidhu and Beri 1989 and Aulakh *et. al*, 2001). In zero tillage systems, crop residues are left on the soil surface. They can be removed, burnt, or left to decay. Rasmussen and Collins (1991) found that retaining crop residues on the soil surface, rather than burning them or incorporating them by tillage, increases organic carbon and total soil nitrogen in the top 5-15 cm of soil. This higher level of carbon and nitrogen in the surface layers was attributed to slower residue decomposition, slower oxidation of soil carbon, and less erosion. Surface retention of residues, moderates soil temperature in winter and summer seasons and help conserve soil moisture such as to improve crop yields.

3.4. Mulching

Rice straw mulching has a significant effect on moisture conservation and weed growth suppression in Zero-till wheat fields. Straw mulching for a short period of 20 DAS or straw mulch retained on the soil surface had similar effects in conserving soil moisture and suppressing weed growth at the early growth stages of the plant. Straw mulch enhanced root growth as indicated by higher values of root length/weight densities as compared to non-mulched plots. N-uptake and apparent N recovery of applied nitrogen and yield of wheat ware significantly higher under mulching as compared to non-mulch conditions (Rahman *et al.*, 2005). It was observed that wheat yield increased when rice straw was left to cover the relay-planted wheat for nine days (Figure 15). The results suggest that where soil moisture is sufficient for surface seeding before harvest of rice crop, it is better for farmers to relay plant and use the harvested rice straw as mulch. Keeping the rice straw mulch not only protects the seed from birds but maintains better soil moisture for germination. Many farmers in fact used this method during their experimentation with surface seeding.

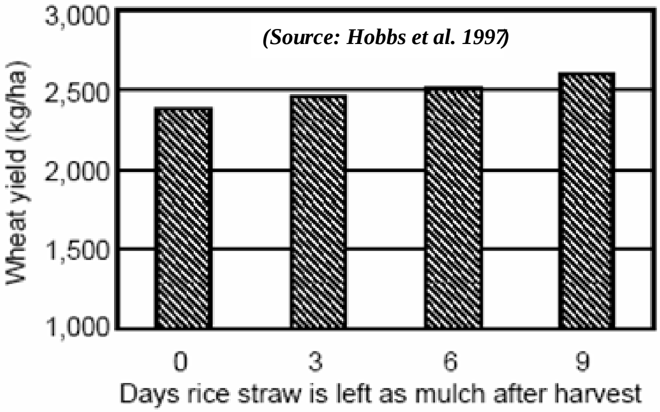


Figure 15: Effectof rice straw retention as mulch on wheat yield.

Results of field experiments conducted in Vietnam on sloping lands have shown that mulching improves productivity of mono-cropping system but long-term cultivation of rice for several years reduces the land productivity. When the rice crop productivity decreases so much that it is no more economical to grow rice, farmers shift to Cassava cultivation, as the last crop, in a cycle of shifting system of cultivation. Data presented in Table 6 also suggest that live mulching (Intercropping) with *Stylosanthes guianensis* improves productivity of cassava crop even on steep slopes. Mulching could be the best way to reduce the soil erosion and surface runoff in the sloping lands. Six ton mulch can almost completely stop the soil erosion from sloppy lands with 10% slope. In addition, to soil erosion and surface runoff, mulch also regulates the soil temperature that could be more beneficial for activity of micro-organisms (Lal, 1989).

Table 6: Effects of soil mulch on crops yields in sloping uplands in SAM-1 Project sites

Cropping system	Yield (t/ha) No- Mulch	Yield (t/ha) With Mulch	% Increase
Mono-Rice cropping (on < 15^{o} degree slopes, no till and direct sowing into the mulch)	0.96 (3Yrs) 0.45(4Yrs)	1,92 1.46	100 224

Cassava (Mono crop on 25 degree slopes) *	18.4	26.9	46

* Living mulch by *Stylosanthes guianensis*.

Soil mulching is not new for Vietnamese farmers they are using rice straw or crop residues to mulch their fields for increasing yield and quality of onion, garlic, root crops and vegetables in plat lands since long. Mulched crops developed better, their yield was higher, and their products had more beautiful appearance and could be sold with higher price. However, farmers in mountainous regions are not familiar with such a technique, but they use to burn every vegetal material left on their fields before sowing. This is one of the most unwanted activities of slash-and-burn practices that we to fight to get rid of. Instead, we have to make most use of vegetal materials (crop residues, weed residues, material brought from other places or deliberately reduced on-the-spot (*in situ* mulch). The materials used as mulch in Vietnam are:

- Crops' residues like rice straw, stems and leaves of maize, soybean, sugarcane leaves,
- Stems and leaves of herbal species like weeds, Chromolaena, Tithonia,
- Wild and semi-wild legumes that have fast growth, high biomass and resistance to pests and diseases (Mucuna, Canavalia, Rice bean, Pueraria);
- Biomass of high yielding grasses like Brachiaria, Panicum, Paspalum, and Pennisetum.

In Vietnam mulching has been done to prevent the soil erosion, improve soil properties, soil moisture conservation during dry periods, control of soil temperature, inhibition of weeds, buildup organic matter and other nutrients in the soil, to facilitate the seed germination, decrease of input in terms of labor for weeding, land preparation and less use of mineral fertilizers, less dependence on weather when arranging sowing dates of second and third crops or inter-crops.

3.5. Organic/Green Manure Management

Use of organic amendments such as farmyard manure (FYM), compost, and plant residues are known to improve soil productivity in rice-wheat cropping system (Chaudhary and Ghildyal 1969; Verma and Bhagat 1992 and Sharma *et al.* 1995). However, the problems frequently encountered in organic manuring are the availability and handling of bulky organic materials. Combined use of inorganic fertilizers and organics invariably helped maintain overall fertility and yields. Application of large quantities of FYM is not feasible due to its lesser available (Singh *et al*., 2004). The challenge is to identify organic sources, which are waste materials with little value as fodder and fuel, and are locally available at a relatively low cost. Lantana biomass and rice straw are useful organic sources for improving soil productivity under rice-wheat cropping. *Lantana* (fresh biomass) incorporation to rice @ 20.30 t ha-1 or rice straw (+ FYM) incorporation to wheat @ 5 t ha-1 each on dry-weight basis, improved productivity of both the crops in sequence. Each treatment also saved chemical nitrogenous fertilizer by 50% during the fourth cropping cycle probably by increasing the size of labile pool of soil organic N. Rice straw has little value as cattle feed (Ponnamperuma 1982), and is readily available in quantities varying from 2-5 t/ha. Similarly, Lantana spp. is a fast-growing weed, encroaching on cultivated lands at an alarming rate in northwestern region. Therefore, these two materials appear potential organic amendments in soils under rice-wheat cropping system (Verma and Sharma, 2000). Green manuring is an attractive practice for meeting the fertilizer N needs of irrigated rice and for improving soil productivity. The adverse effects of wheat or rice straw can be successfully counteracted by combined incorporation of GM and crop residues into the soil before transplanting rice. Apart from increasing soil organic matter content, crop residues add significant quantities of plant nutrients in soil. Green manuring results in small effects on organic matter content of soil in rice-wheat rotation under subtropical conditions. Farmyard manure plays an important role in supplying plant nutrients and enhancing soil productivity (Singh *et al.*, 2000). Use of crop residues and green manure not only regulate the fertility aspect of soil but also improve the physical characteristics like formation of water stable aggregates, particularly > 2 mm size infiltration rate (Figure 16). Combined application of Green Manure and wide C: N ratio straw materials had the highest improvement on infiltration rates than their separate applications. This may be due to improvement in soil structure and formation of channels after the decay of root of the GM crop (Sharma *et al.* 1987).

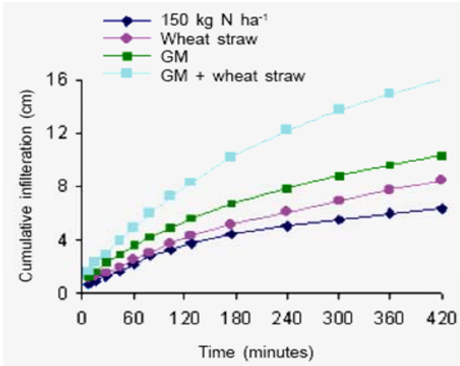


Figure 16: Effect of green manure and crop residue recycling on infiltration after harvest of rice in rice -wheat system. ***(Source: Singh et al, 2000).***

3.6. Brown Manuring and 'Double No-Till' Agriculture

Despite known benefits of green manuring, farmers could never benefit from the practice due to non-availability of water in the dams in peak summers when the crop is grown. In 'brown manuring' a green manure crop such as *Dhaincha* is simultaneously co-cultured with rice and allowed to grow for 30-35 days before it is knocked down with 2-4D herbicide (Figure 17). Farmers by and large like this practice as it help them i) provide a surface soil cover during monsoon season without additional need for irrigation water, ii) save 20-30 kg/ha of N, iii) reduce weed population by half, and iv) facilitates a shift from puddled transplanted rice to direct seeded rice. Brown manuring practice, developed very recently together with hundreds of farmers, bridges the missing link in RCTs by providing a surface cover so vital to conservation agriculture. This practice can be promoted in monsoon (*Kharif)* season in many more areas, outside the IGP.

Figure 17:Sesbania co-culture in rice for brown manuring.

3.7. Terrace and Mulch based technique on sloppy lands:

In landscapes with slopes more than 15^o, soil and water conservation measures essentially include some engineering measures with preparation of terraces. This helps break slopes at short intervals such as to reduce runoff and sediment loss from the fields during monsoon season. However, the Vietnamese experience (Tuan et al, 2003) for the landscape with < 15^o slopes indicates that there may not be any big advantage of opting for terrace cultivation if no-till agriculture is practiced with surface retention of the residues (Table 7).

Table 7: Yields of rice and maize crops grown at < 15^o slope on terraced and un-terraced fields.

Technology	Grain Yields (kg/ha)			
Variety	No terrace (sloppy lands) + Mulch	No terrace (sloppy lands) + No mulch	Terrace + mulch	Terrace + No mulch
Dam Bao (Rice)	2250	1250	2136	1550
LVN10 (Maize)	5950	3725	2112*	1326

* Lower yields due to shifting of soil during terracing.

Similar type of experience was also noticed by VASI-CIRAD team in other field experiment conducted on sloppy lands with different rice genotypes with and without terrace and mulch (Table 8).

Table8.Effects of mulch on rice yield (t/ha) on sloping lands having less than 15^o slopes.

Techniques	**Mulching**	**Variety Dam Bao**	**CIRAD 141**	**8 FA 337-1**
No terrace	-	1.70	1.59	1.83
No terrace	+	2.59	1.89	2.21
Terrace	-	2.81	-	-
Terrace	+	3.63	1.95	-

(Source: Annual report of VASI-CIRAD-EUSLLC-RDP, 2003)

On the basis common knowledge, it is also advocated that cultivation should be along the contours such as to facilitate soil and water conservation. Farmers, generally however are not enamored to follow such recommendations. In Vietnam, about 30% farmers practice up and down cultivation. They do so because overflowing runoff water across the slope damages the terrace and also uproots /knocks down many plants reducing their population. Besides being easy to seed, up and down cultivation has no such ill effect on plant population. Though more research is needed but it seems that controlled traffic lanes which are properly mulched, can serve as effective waterways for promoting up-down cultivation in gently sloping lands.

3.8 Weed/ Pest management

In general there is a symbiotic relationship between wetland rice and dryland crops, particularly non-cereals and rice crop breaks the cycle of viral diseases, insect pests, and weeds of upland crops (Litsinger 1993). The major weed species affecting wheat, *Phalaris minor,* is normally controlled using the herbicide isoproturon, which is not always effective. Farmers do not always apply *isoproturon* well or on time; in addition, recent reports have confirmed that *P.*

minor has developed *isoproturon* resistance (Malik 1996). Alternative integrated weed strategies must be developed to overcome this problem. Preliminary observations indicate that *P. minor* is less prolific on dry tops of raised beds than on the wetter soil found in conventional flat bed planting. Weeds can also be reduced by cultivating between the beds. Thus bed planting provides farmers with additional options for controlling weeds (Hobbs *et al.*, 1997). Inter-cropping of Sesbania with rice for "brown manuring" surface mulching and use of pre-emergence herbicides all helped in reducing the weed problems with much less use of water. It has been reported that by the adoption of Zero-tillage practice weeds populationcanbereduced

Table 9: Effects on plant emergence and weed density of zero tillage and farmers' practice for establishment of wheat after rice, Punjab, Pakistan

Tillage methods	Plant population.m^{-2}			
	Wheat	Grassy weeds	Broadleaf weeds	Total
Zero-tillage	**114[a]**	**59[b]**	**54[b]**	**113[a]**
Farmers' practice	**96[b]**	**72[a]**	**90[a]**	**162[b]**
Values followed by the same letter do not differ significantly at 5% level. (Source: Aslam et al., 1993)				

Until recently information on weed management in direct seeded rice was sketchy. Samar et al., (2005) have indicated that the major weeds associated with dry seeded rice on FIRBS during both the seasons were: *Echinochloa crus-galli* (L.) P. Beauv., *Echinochloa colona* (L.) Link, *Dactyloctenium aegyptium* (L.) Willd, *Leptochloa panacea* (Retz.) Ohwl; *Caesulia axillaris* Roxb., *Euphorbia hirta* L., *Lindernia* sp., *Commelina benghalensis* L., *Eclipta prostrata* (L.) L., *Trianthema portulacastrum* L., and *Portulaca oleraceae* L.

Results of field studies have indicated that these weed species can be effectively controlled through use of Triclopyr @ 500 g. a.i. ha^{-1}., bensulfuron @ 60 g a.i. ha^{-1}, ethoxysulfuron @ 18 g a.i. ha^{-1}. and 2,4-D (Ester) @ 500 g a.i. ha^{-1}. When applied at 21 days after seeding (DAS) the above chemical molecules were found equally effective in realizing higher rice grain yields by controlling broadleaf weeds in dry seeded rice cultivated on flats of raised beds. Among these, ethoxysulfuron 18 g a.i.ha^{-1} was found inexpensive and effective for controlling broadleaf weeds in dry seeded rice on FIRBS, in broadleaf weeds predominant areas. Several preemergence herbicides viz: butachlor, pendimethalin, oxadiazon, oxyfluorfen, and nitrofen alone or supplemented with hand weeding have been reported to provide a fair degree of weed control (Moorthy and Manna, 1993; Samar et al 2005, and Govind et al. 2004).

3.9. Diversification

Rising incomes, growing urbanization, changing relative prices of cereals and non-cereal foods and changing tastes are leading to diet diversification in the South Asian countries away from cereals and towards high value agriculture including fruits, vegetables, dairy, meat, eggs, and fish (Aggarwal *et al.*, 2004). Studies have also shown that high-value commodities offer immense opportunities to increase income level of small holders, generate employment opportunities, and improve the productivity of insufficient resources (Joshi *et al.*, 2002). The emerging opportunities of agricultural diversification towards high-value commodities need to be harnessed for the benefit of smallholders and rural poor in the IGP. Production of high-value commodities (fruits, vegetables, milk, meat, eggs, and fish) increased at a much faster rate than food grain commodities in South Asia during the 1990s. For example, growth in production of milk, poultry and fruits during the 1990s increased more than 5% per annum as compared to 2.45% for cereals (Joshi *et al.*, 2002). The export of these commodities from South Asian countries has witnessed a quantum jump. A gradual shift in the production portfolio towards high value commodities and away from rice cultivation could also result in reducing groundwater pumping (mainly in the western IGP) which both would help in striking the decline in the water table and reduce fossil fuel usage.

A number of studies have been available on systems' diversification at the farm level related to identification of crops, technologies and market niches. In terms of policy development, promotion of diversification would require knowledge on its possible implications on income, employment, resource conservation, and linkages between production and marketing. It was reported that diversification of rice-wheat system could be possible with adoption of bed planting, especially by growing oilseed and pulses. This planting technique provides opportunity to take succeeding crop on the same bed just by reshaping. Crop sequences having high value crops with rice/wheat and greater cropping intensity recorded higher net return and sustainable value index. The system's diversification also reduced the weed population especially *Phalaris minor* in subsequent wheat cycle due to growing berseem in previous year.

A significant feature of land diversification in the upper IGP has been the conversion of grazing and uncultivated salt affected (saline and alkali) areas into crop land following availability of appropriate technologies and overall control of groundwater tables as a result of large scale installation of tubewells. In the past three decades nearly 1.5 million ha of alkali land were reclaimed in the state of Punjab, Haryana and Uttar Pradesh. Reduction in grazing land has reflected in livestock population and in turn availability of manure for maintenance of soil fertility and crop productivity (Gupta and Abrol, 2000). The attribute of land diversification in middle and lower IGP that is more prone to floods and drought. Many lowlands with excessive moisture and waterlogging problems are generally used for growing pulse crops such as lentil and chickpea using surface seeding methods. (Rai, 2002). Some of the progressive farmers in this region have started taking summer rice (April-June) along with rice and wheat in the main season (Aggarwal *et al.*, 2000).

In low lying areas of eastern UP, Bihar (India) and parts of Bangladesh where water recedes late or soils remain wet for long, farmers seed lentil, peas and wheat on drying paddies a couple of days before harvest of rice (Razzaque *et al.* 1995 and Gupta *et al.* 2002). In comparison to north-western IGP, eastern farmers diversify the R-W systems more to covers risks of drought-flood prone agriculture. Many farmers replace wheat by oilseeds (*Brassica juncea or napus*), pulses (pea, *Pisum sativum*), grass pea (*Lathyrus spp.),* chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), potato or sugarcane and occasionally rice by pigeon pea (*Cajanus cajan*), maize, sunflower, soybeans and sorghum. Winter maize is also popular in eastern parts of the Gangetic Plains in Bihar and UP, and Bangladesh.

In a three-year study, eight crop sequences were tested for their profitability. Results indicated that diversification of rice -wheat system, once in three years, always enhanced the net return. Inclusion of oilseed or pulses once in three years led to higher profits as compared to conventional rice-wheat system (Tripathi et al, 2004). In a recent farmers participatory trial conducted by Connor *et al.* (2003) it was observed that raised bed planting of crops improved crop yields: maize (37.4 %), urdbean (33.6), mungbean (21.8 %), greenpeas (14.5 %), wheat (6.4 %), rice (6.2 %), pigeon pea (46.7 %) and gram (37.0 %) as compared to flat planting. Moreover, there was a saving of 26 to 42 % water under bed as compared to flat planting by various crops.

4. Concepts and elements of Conservation Agriculture and RCTs

Globalization and urbanization, becoming more pervasive in recent years, has changed the paradigm for agriculture. The change is perceived to be a fundamental shift from the age-old paradigm based on massive soil inversion with a plow to a new paradigm of conservation agriculture, whose best exponent is 'resource conserving technologies (RCTs)' or some times even referred to by zero-tillage. With the rapid expansion of zero-till wheat in the Indo-Gangetic Plains, there has been a surge of interest in resource conserving technologies (RCTs). Resource conserving technologies refer to those practices that enhance resource- or input-use efficiency (Harrington and Erenstein, 2005). Zero or reduced tillage or raised bed planting practices that save fuel and improve plot-level water productivity or precision land-leveling that help save water are also considered RCTs. New varieties or the agronomic practices or use of leaf color charts (LCC) that allow the use of nitrogen more efficiently, may also be considered RCTs. The practice of controlled traffic which minimizes soil compaction or the paired row planting practice which helps improve yields can all be considered as examples of RCTs. There are many, many more. RCTs, which includes zero-tillage as a key element, is a complete soil and crop management system, sensitive to local situations and resource endowments of the farmers. The RCTs package has 'divisibility' in application and utility in diverse situations.

In contrast, "conservation agriculture (CA)" practices refer to those RCTs with the following characteristics:

- Soil cover, particularly through the retention of crop residues on the soil surface,
- Sensible, profitable rotations, and
- A minimum level of soil movement, e.g., reduced or zero tillage.

Over the past 2-3 decades globally, conservation agriculture has emerged as a way for evolution to the sustainability of intensive production systems. The term 'Conservation Agriculture' (CA) refers to the system of raising crops without tilling the soil while retaining crop residues on the soil surface. Land preparation through precision land leveling and bed and furrow configuration for planting crops further enable improved resource management. Conservation agriculture mainly include soil management practices, which permit the management of the soil for agricultural uses, without disturbing the soil's structure, composition and natural biodiversity, while protecting it from the processes that are involved in the degradation of these resources, like soil erosion and degradation and water contamination. In conventional systems soil tillage is a necessary requirement to produce a crop, while tillage does not form a part of this production strategy in CA. In the conventional system involving intensive tillage, there is a gradual decline in soil organic matter through accelerated oxidation and through burning of crop residues causing pollution, GHG emissions and loss of valuable plant nutrients. When the crop residues are retained on soil surface in combination with no tillage, it initiates processes that led to improved soil quality and overall resource improvement.

In the above elements of CA, an important element of controlled-traffic seems to be missing. Free-wheeling of tractors during planting and harvesting operations makes ruts and spoils the level in moist rice fields, compact the soils, forcing farmers early to go in for tillage. Therefore, controlled traffic should form an integral part of CA to be sustainable. The important distinction between zerotill based RCTs and CA is that the former is attractive to the farmers in the near-term, as it provides immediate gains to them, but may be unsustainable in the longer-term. An example of this is the use zero-till wheat followed by puddled transplanted rice or zero tillage without residue retention. For the past several years farmers in the IGP, have been practicing puddled transplanted rice and zero till wheat but the near-term benefits of zerotill wheat have now moving farmers to adopt double no-till.

Conservation agriculture permits management of soils for agricultural production without excessively disturbing the soil and while protecting it from the processes that contribute to degradation e.g. erosion, compaction, aggregate breakdown etc. Conservation agriculture is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and environment, an example of a win-win situation. Benefits of CA have been demonstrated through its large scale adoption in many socio-economic and agro-ecological situations in different countries the world over.

4.1. Benefits to farmers

Reduced cultivation cost, through savings in labour, time and farm power

- Improved and stable yields with reduced use of inputs (fertilizers, pesticides)
- In case of mechanized farms, longer lifetime and less repair of tractors, less power and much lower fuel consumption
- Benefits of CA come about over a period of time and in some cases, might appear less profitable in the initial years

4.2. Benefits to natural resources

- Reduced soil degradation through reduced impact of rainfall, structural breakdown, reduced erosion and runoff,
- Gradual decomposition of surface residues leading to increased organic matter and biological activity resulting in improved capacity of soils to retain and regulate water and nutrient availability and supply
- Improved biological activity and diversity in the soil, including natural predators and competitors.
- Reduced pollution of surface and ground water from chemical and pesticides, resulting from improved inputs use efficiency
- Savings in non–renewable energy use and increased Carbon sequestration.

Conservation agriculture is aimed at reverting the process of degradation inherent to the conventional agricultural practices like intensive cultivation, burning and incorporation of crop residues; aggressive seed bed preparation, with heavy machinery lead to declining soil fertility, biodiversity and erosion. CA leads to sustainable improvement in the use of water efficiently by improving infiltration, reducing evaporation losses and improving the quality and availability of ground and surface water

4.3. Conservation Agriculture: Asian Scenario

Efforts to adapt and promote resource conservation technologies in IGP have been underway for nearly a decade but it is only in the past 4 to 5 years that the technologies are finding accelerated acceptance by the farmers. Efforts have been made to develop and extend conservation agriculture in IGP through the combined initiatives of several SAUs, department of agriculture in states, Agricultural Research Councils of Pakistan, India, Bangladesh and Nepal, CG centers (CIMMYT, IRRI and ICRISAT) in partnership with the Rice-Wheat consortium for the Indo-Gangetic Plains (RWC). Unlike, in the rest of the world, spread of RCTs is taking place in the irrigated regions where rice-wheat cropping system, having contrasting edaphic requirements, predominates. CA systems are yet to be rooted in the rainfed agro-ecoregion which constitutes the bulk of the acreage in agriculture in South Asia. Zero-tillage and bed planting have the potential for saving water but the extent of savings at different levels (field , farm and water course levels) and its likely impact of the restoration of regional hydrological sustainability are little known. Conservation agriculture not only increase yield and input use efficiencies, but also reduces the incidence of weeds by 46% in the R-W systems. Positive effect was noticed for laser leveler in improving crop establishment, uniformity of crop maturity, increases in irrigated cultivable area by 3% (in canal commands) and upto 6% (in tubewell irrigated areas), improves water application efficiency upto 50%, and water productivity and yields of crops (15 to 25%), increase in nutrient use efficiency (15-25%), weeds control etc,. (CASA, 2004). Due to the above mentioned benefits, adoption of RCTs is increasing at a very fast speed. Resource conservation technologies such as aerobic cultivation of rice on raised beds enable farmers to grow rice overcome ill effects of puddling the soils.

5. Paradigm - Shifts and strategic entry points?

5.1. Till- to No-till Systems

In the Rice-Wheat cropping system, the two crops have contrasting edaphic requirements. Whereas, rice is commonly transplanted into puddled soils and gets continued submergence, wheat is grown in upland well drained soils, having good tilth. Puddling reduces infiltration of water but destroys soil structure. Expecting a better wheat crop, farmers generally do 6-8 preparatory ploughings in rice drying soils to achieve good seed bed. However, excessive tillage results in late planting and reduced yields of wheat. The turn around time between rice and wheat crops is 3- 6 weeks. In order to timely plant wheat, many farmers harvest the rice crop with a combine and burn loose residues. Burning releases greenhouse gases and particulate matter in large quantities in sudden spurts. This deteriorates the air quality and results in significant losses of nutrients (Sharma and Mishra, 2001).

Surface seeding is the simplest zero-tillage system being promoted. In this tillage option, seeds of crops are tossed onto a water saturated soil surface without any land preparation. This is a traditional farmer practice for wheat, legume, and other crop establishment in parts of eastern India and Bangladesh (Catling *et al.*, 1983). Wheat seed is either broadcast before the rice crop is harvested (relay-planted) or after harvest. Direct seeding of rice saves energy and water for rice establishment and eliminates labour in transplanting. It can result in earlier maturity of rice, which helps improve wheat productivity through timelier establishment.

Zero-till wheat is now an established crop management activity for farmers in rice-wheat areas of NW-IGP. This is another RCT, in which the seed is placed into the soil by a seed drill without prior land preparation. This technology, which has been tested in various regions of IGP (Sheikh *et al.*, 1993; Aslam *et al.*, 1993), is more relevant in the higher-yielding, more mechanized areas of northwest India and Pakistan, where most land preparation is now done with four-wheel tractors. Environmental benefits will increase as the new second generation seed drills become accessible to farmers to experiment. The new drills have the ability to plant into loose residue instead of burning them.

Bed planting will also grow in popularity as more machinery and more farmers experiment with it. Permanent bed planting will cut costs, improve yields and drastically reduce natural resource use, especially water but also fertilizer and other inputs. The technology needs to be adapted to smaller two-wheel and animal drawn systems that would be more reasonable for the resource poor farmers of the eastern IGP where plot size is also much smaller. Issues of weed carryover from the rice crop to the wheat crop will also be more important in the areas of eastern part of IGP. Land levelling further enhances the benefits in zerotill and bed planting systems in terms of water savings, improved crop stands and yields (Hobbs *et al.*, 2001). Zero-till helps solve the problem of late planting and excessive costs of production in wheat, but if rice can be grown without puddling, the total system productivity would be even greater. Changing from transplanted, puddled rice to direct seeded aerobic rice would also reduce methane emissions significantly, a green house gas that is 21 times more effective than carbon dioxide (Grace *et al.* 2003).

5.2. Crop residue burning to management/ retention/mulching

Crop residue is a vital natural resource for conserving and sustaining soil productivity. It is the primary substrate for replenishment of soil organic matter. Leading mineralization, crop residue supplies essential plant nutrients. Moreover, residue incorporation can improve physical and biological conditions of the soil and prevent soil degradation. In the IGP, large amounts of crop residue are burned or removed after harvest (Smil, 1999). This results in loss of organic matter and nutrients and causes atmospheric pollution due to emissions of toxic and greenhouse gases such as CO, CO_2, and CH_4, which pose a threat to human and ecosystem health (Nguyen *et al.*, 1994). Demand for crop residue used for cooking fuel and animal feed is high in this region (Bronson *et al.*, 1998). Removal or burning of residue ensures farmers' quick seedbed preparation and avoids the risk of reduced crop yields associated with incorporating wide C/N ratio residue that immobilizes N during decomposition (Beri *et al.*, 1995). The benefits of sequestering soil organic carbon to sustaining crop productivity by applying organic amendments and crop residue and including legumes in crop rotations have been well documented in the temperate regions. As there have been increase in the area under high yielding varieties with widespread adoption of green revolution technologies it also lead to increase in both crop as well as straw yield in RWS (rice-wheat system) in India. Advancement in the technological implements in the form of combined harvesting technologies, have become common and leave behind large quantities of straw. A total of about 78 and 85 million tons dry rice and wheat straw are generated in India alone in the year 2000 (Gupta *et al.,* 2004). In case of combine harvesting almost all portion of the residue generated

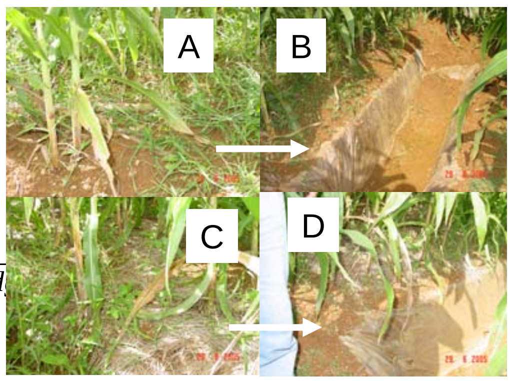


Figure 18: Effect of rice straw mulching on weed population and soil loss from maize field on sloppy lands in Vietnam.

is left in the field as loose straw that finally end up in burning as there is very small time available between harvesting of rice and planting of wheat and moreover performance of the wheat crop is highly susceptible to any delay in planting.

Rice straw mulching has a significant effect on soil and moisture conservation and weed growth suppression in Zero-till/sloppy land fields (Figure 18). As seen in figure the field having no straw mulch (A) offer more weed population and higher soil losses (B) as compared to mulched field (C & D). Straw mulching for a short period of 20 DAS or straw mulch retained on the soil surface had similar effects in conserving soil moisture and suppressing weed growth at the early growth stages of the plant. Straw mulch enhanced root growth as indicated by higher values of root length density and root weight density under mulching as compared to non-mulched plots. Nitrogen uptake and applied nitrogen recovery (%) was significantly higher under mulching as compared to non-mulch conditions. A significant interaction of mulching and nitrogen levels was found for the grain yield of wheat. Considering the recycling of organic C and long-term effects on soil properties the rice straw mulch should be incorporated in the soil. However, from the point of the competitive and multiple use of rice straw, farmers might choose the alternative option of using straw mulch for a short period of 20 DAS and thereafter for fuel (Rahman *et al*, 2005).

6. Driving forces for CA/RCTs

6.1. Population pressure

Globalization and urbanization are becoming pervasive. Prime irrigated lands and water resources are being diverted to other sectors of national economies. The last few decades have witnessed a steep rise in population pressure and land degradation. Concerns of sustainable management of natural resources are rising and so has the food and nutritional security challenges. Poor land, water and crop management practices are at the heart of these declines. If there is one thing on which most experts would agree, it is that we are in a time of great change. The change is perceived to be so fundamental. The paradigm shift is all about the way agricultural research is prioritized, conducted and managed, and knowledge-intensive technologies are transferred to farmers. These shifts include a change over from the commodity-centric approach to system ecology research; an area general to location specific recommendations; developing consensus on national and regional priorities at the 'Top down' to a 'Bottom-up' planning processes in participatory mode with farmers. It calls for reforms in research management processes, re-focusing the role of public and private sectors, fostering institutional and disciplinary pluralisms to harness synergy for tackling complex problems of natural resource management (NRM).

6.2. Producing more at reduced costs

Resource conservation technologies related to tillage practices (zero/bed planting/ direct seeding etc.) on one hand afford time for optimum sowing and other hand drastically reduces the consumption of fossil fuels, which significantly reduce carbon emissions into the atmosphere and the risk of global warming, and the wear and tear of tractor parts and accessories (Hobbs *et al.*, 2002). Farm mechanization also reduced the cost of cultivation through minimizing the labour cost at peak time like sowing and harvesting. The above description suggests that the strategy of producing more food at subsidized costs should be reoriented to systems that produce more at less cost and obviate negative impacts on land, water and environmental quality. It also calls for a new suite of technologies that help poor farmers improve their livelihoods. Research to identify constraints to technology adoption by smallholder farmers will facilitate speedy remediation of the above. The use of genetic enhancement of traits combined with relevant management systems of particular importance to the poor will help them produce high-value crop and livestock commodities and products that can lead to better incomes if markets for excess production can be identified. Integrated crop-livestock, land and water management research to facilitate agro-ecological intensification both in low and high potential environments combined with marketing will help smallholder farmers escape poverty, improve employment, make more food available at lower prices, reduce social conflicts and improve social security. Such an approach will help generate alternate sources of productivity growth, enhance incomes for the poor farmers and contribute to CGIAR research in prioritized areas and the Millennium Development Goals (MDG).

6.3. More divergent pro-poor cropping systems

The Rice-Wheat Consortium has been promoting system diversification-including the addition of crops such as maize, sugarcane, legumes, potatoes, and vegetables-to enhance farmers' incomes and make production more sustainable. In the lower IGP (region 4 and 5) that includes Bihar and eastern Uttar Pradesh and parts of Bangladesh, a region characterized by resource-poor, small-scale farmers, maize cropping under zero-tillage during the dry, winter season has proven successful (RWC-Research Highlights, 2001-2003). Dribbling of maize with potato planted on the ridges with an indigenous mechanical planter has been liked by many farmers as it helps improve yield of potato and quality of the tubers besides reducing cost of potato cultivation by US $ 50-100. Intercropped maize subsequently grows very well on the residual fertility in potato fields. Boro-rice (highest yielding rice crop in rice systems of South Asia) is being promoted as an additional crop in flood-prone, poorly-drained areas (*Tal lands*) in the East where a single, low yielding crop of rice is normally grown in monsoon season. Efforts are on to relocate highly productive Boro rice crop in irrigated midlands and uplands rice ecologies on the raised beds to save on irrigation water. Chickpea, lentils, pigeonpea Mungbean and other legumes are being promoted in *Chaur and Diara lands*”, with improved varieties and management (zero-tillage and beds), to improve the returns.

6.4. Availability of adapted farm machineries

Mechanization has increased gradually from west to east over the past 30 years (government statistics for the region). Small four-wheel tractors in northwestern India and Pakistan do most land preparation with farmers who don’t own tractors and who rent them from service providers. However, in the east, many farmers still rely on animal power for land preparation. This is also changing since it is becoming expensive to keep a pair of bullocks for a year for this purpose. Two-wheel tractors are becoming popular on the small farms and fields in Bangladesh. There is also the question of status, with the use of tractors having a higher status than animals (Hobbs and Gupta, 2003). To the contrary, adoption of RTC's could be even faster if it were possible to have sufficient machinery available from small-scale manufacturers. Farmers are now in possession of more than 20,000 zero-tillage drills (up from only 4,000 in

2001) made by 68 manufacturers (compared to 32 in 2001). Adoption of zero-tillage could exceed several million hectares in a few years, as local manufacturers meet the demand for machinery, farmers share insights, and knowledge of the benefits spreads (RWC-Highlights, 2003-04).

6.5. Herbicide resistance in weeds

The serious yield losses due to incidence of *Phalaris minor* in mid 1970s were exceptional. To protect the enormous losses caused by this weed on a massive scale in rice-wheat cropping system in northwest IGP in India the use of herbicides became a common practice. However, frequent use of same herbicide turned out to spread *Phalaris* further due to development of resistance in 1992 (Malik and Singh, 1995). For the last 10 years, farmers have faced serious problem of herbicide resistance, thereby replacing isoproturon with new herbicides. Weed scientists have been investigating the resistance development in different biotypes of *P. minor* from 1991 onward. After reporting resistance in 1992-93, many biotypes have been found resistant to isoproturon (Malik, 1996, Yadav *et al.,* 1997; and Balyan *et al.,* 1997). Herbicide resistant weeds especially *Phalaris minor* resistance in India vulnerable to the continuing success of herbicide technology in rice-wheat cropping system. In early 1980s, farmers were desperate to use herbicides because herbicides could overcome the problem of heavy infestation of *Phalaris minor*. Similarly, in mid 1990s farmers were worried about overcoming the barrier of herbicide resistance through integrated weed management so that the pressure of rich seed bank of this weed could be contained. From 1992 to 1996, herbicide resistance damaged the farmer's capacity to feed the nation and many farmers in the nastiest affected areas went out of order. Such inefficiencies in rice-wheat cropping system were more intolerable than ever. Modern varieties thrived on the strength of herbicides, but system ecology continued favoring *Phalaris*. Herbicide resistance due to long-term inefficiencies of chemical weed control pressed scientists to integrate zero-tillage with herbicides. The introduction of alternate herbicides at present has weathered the losses in wheat productivity due to herbicide resistance. The prices of these herbicides are likely to remain high in the medium term. In consequence, the management of herbicide resistance as of today can be labeled with yield increases upto 800-900 kg/ha at farmers' fields.

6.6. Improvement in quality of land and water resources, environmental quality

Low quality waters are often used in cyclic mode in the Indo-Gangetic plains. At times they are blended with canal water in water courses to improve the total water supply and also the flow rates. Blending of low and good quality waters have earlier been discouraged because of their adverse effect on crop productivity. However, if the resultant electrical conductivity of the blended water supplies is less than the threshold conductivity, they can be used safely. In combination with new RCTs, blending of water multi-quality water supplies in on-farm water storage reservoirs not only improves the quality of waters having residual sodium carbonates and overcome problems associated with nightthis water, but can also improve the use of rainwater and water productivity and yields of a bed planted wheat crop. Preliminary results of a trial conducted in Pakistan have been very encouraging. Bed planting system also offers scope for use of even the saline waters. When saline waters are applied in raised bed-furrow land configuration, it permits salt movement to the top of the raised beds keeping the rootzone relatively free of salts at the sill and below the furrow. This improves the ability of the plants to avoid early salt injury at seedling stage and subsequently improve salt tolerance of the crop due to crop ontogeny. Bed planting when combined with mulching or residue retention has the potential to reduce evaporation losses from the soil surface, salinization and further improve crop productivity in saline environments. Adoption of RCTs is not adversely affecting soil biology. Nematodes, which have been thought to effect grain yield production, were not found in significant numbers possibly as a result of the regular flooding that takes place in the rice crops (Duveiller *et al.*, 2004).

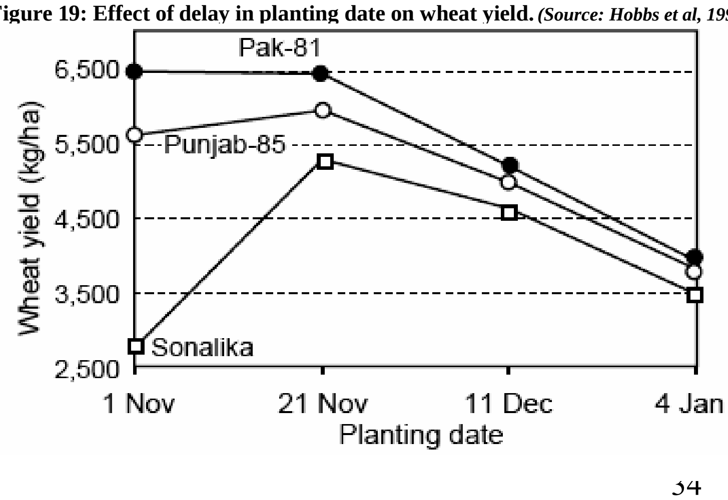
Sloping lands are distributed in all 9 ecological regions of Vietnam, but mostly in the Northern mountainous, Central and Tay Nguyen regions. Most of gentle slopes of less than 15^o (accounting for 21.9%) have been used for agricultural and forestry production. The lands with 15^o to 25^o sloppiness occupy 16.4%. The rest 61.7% are very steep (more than 25%). Due to the lack of production lands, mountainous farmers have to cultivate food crops in very steep slopes of more than 25$^{o.}$. On such slopes, soil erosion occurs at very high speed, so the time for productive cultivation is short, usually 2 or 3 seasons of short cycle crops, followed by cassava that is planted as the last crop of a cultivation cycle. Due to population pressure, the fallow periods are commonly reduced from more than 25 years to 5 and 3 years that are not long enough for soil fertility to be recovered. So, the crop yields are generally low. Most of the gentle slopes have past through too many crop-fallow cycles with soil being reduced after each cycle. On this slopes, the constraints to crops are not only poor nutrition, but also soil toxicity, soil compaction. They are left as bare hills and lands with very poor vegetal cover.

7. Production practices of Conservation Agriculture

7.1. Crop establishment and residue management

Rice and wheat cannot utilize water and nutrients efficiently for high yield unless they are planted on time and good plant stands are achieved. A major constraint on timely planting and good plant stands is the long time it takes to plough the field for wheat after a crop of rice. Under the conventional method rice has been transplanted after puddling of soil that restricts the infiltration but also destroys the soil structure, while wheat sown in well tilled soil. The major drawback in conventional method of crop establishment in consumed much labour and investment and most of the time wheat sowing delayed due to excessive/less soil moisture. It has been quantified that wheat grain yield declines nearly 1.5% per day of delay in sowing after 2nd week of November in Indian Punjab (Ortiz-Monasterio *et al.* 1993). The yield losses are much more (about 63kg/day/ha) in eastern parts of the Gangetic plains. Similar effect of delayed planting of wheat on yield was also noticed in Punjab, Pakistan (Figure 19). Timely planting of crops also has the advantage that un-timely rains do not interfere with harvesting- threshing operations for wheat. With these distinct problems farmers' in IGP are adopting conservation tillage options (zero/reduce/bed planting

Figure 19: Effect of delay in planting date on wheat yield. ***(Source: Hobbs et al, 1997)***



etc.) for crop establishment. It has been analyzed that there are three distinct periods of moisture availability in Eastern IGP. The early moist period (evaporation exceeds rainfall) extends over 12-18 days followed by 93-139 days of humid moist period wherein precipitation exceeds potential evapo-transpiration. This is followed by a moist period of 17-22 days where once again rainfall is less than evapo-transpiration. If the rice seedlings and crop can be established early in the first moist period, before the humid period, the rice crop can benefit from the monsoon rain and grow without the need for irrigation. Timely transplanting of rice also results in earlier harvests and allows timely planting of the next wheat crop. The results of farmer participatory field trials showed that the strategy of timely transplanting of rice improves wheat yields. Rice wheat system productivity was nearly 12-13 tons per ha when rice was transplanted before 28th June. This was reduced by more than 40% when fields were planted after 15th August (Hobbs and Gupta, 2003). Recent research shows that by using zero and reduced tillage options, wheat can be planted on time at reduced cost without sacrificing yield (Hobbs et al, 1998, Gupta *et al.*, 2000, Hobbs and Gupta, 2003). Bed planting, especially permanent beds, is gaining acceptance, as more farmers receive equipment to experiment and see the benefits for themselves. Data from India suggest that use of permanent beds saves even more water (average 31%) than zero-tillage. The practice also improves yields (24%) across an array of crops, increases input- use efficiency, and cuts costs (Table). Finally, soil physical and biological properties improve under permanent beds.

7.2. Integrated Nutrient management

High yields are not possible unless adequate nutrients are taken up by plants. Nutrients can come from the soil or fertilizer, either organic or inorganic. The important concept is to increase the efficiency of the applied nutrients. A rice crop yielding 6 t/ha and wheat crop yielding 5 t/ha removes (g/ha) 915 & 3, 100 iron, 4, 500 & 350 manganese, 240 & 280 zinc, 110 & 120 copper, 90 & 240 boron and 12 & 12 molybdenum (Kanwar 1998).The potential could be achieved through the balanced use of nutrients. If any one nutrient becomes limiting, it will limit the efficiency of others (Abrol, *et al*, 2000). Farmers will probably need to rely on a combination of organic and inorganic sources of nutrients, because there is not sufficient organic manure to provide the needed yield growth, and the cost of hauling organic manures is high. Proper timing of nutrients can help increase efficiency (Hobbs and Adhikary, 1998). It is obvious that any technology that can increase the efficiency of applied inputs can significantly reduce the fertilizer requirements. In the northwest Indo-Gangetic alluvial plains sodic or alkali soils characterize by excess of exchangeable sodium, high pH, and adverse soil physical properties occur widely. Alkali soils contain high amounts of extractable P and due to high pH or ESP have low P absorption capacity. Hence, farmers undertaking reclamation of alkali soils and practicing rice-wheat crop rotation can economize on fertilizer P by skipping its application in the initial 3 to 5 years without any loss in yield. Because of application of amendments and growing of wetland rice, there is decrease in extractable P in the surface soil (Chhabra and Thakur, 2000). The analysis of yield trends of LTE in Bangladesh, China, India and Nepal suggest that although significant yield decline is not widespread, yields of both rice and wheat are stagnant. In the rice-wheat system, particularly in IGP, rice yield are declining more rapidly than wheat. The causes of yield decline are mostly location specific but depletion of soil K seems to be most common (Ladha *et al,* 2003). Long-term study suggests that 120 kg N/ha should be applied to both rice and wheat to get optimum yields in reclaimed sodic soils. Phosphorus at the rate of 22 kg P/ha should be given to rice only when available P in top 15 cm soil depth has come down to 12.7 kg

P/ha. There is no need to apply K in reclaimed sodic soils since they contain high available K and there occurs large contribution of non-exchangeable K towards total K uptake by crops (Singh and Swarup, 2000). Nutritional requirements of the crops in rice-wheat sequence can be met with a combination of inorganic and organic sources in 50:50 or 75:25 to rice, and in wheat 100% recommended NPK has to be applied through inorganic source to get highest yields (Rekhi *et al.*, 2000). It was found that current recommendation fertilizer-N scheduling should be revised for better agronomic efficiency (Singh *et al.* 2002).The chlorophyll meter–based N management in rice can save 12.5 to 25% of the existing fertilizer N recommendation with no yield loss. Decrease in crop productivity over the years with intensive cropping could be largely traced in the deficiency of N and Zn, probable toxicity of Fe and Mn, and nutrient imbalance due to antagonism. Corrective measures such as curtailing P application where the build-up is noticeably high and raising the quantities of FYM and Zn are needed (Ram, 2000). The analysis of LTE with manure or straw treatments indicate that regular use of organic amendments (OA) did not improve grain yield in rice-rice and rice-wheat cropping systems but it could be profitable, provided the organic materials are used as a complement to a recommended doses of inorganic NPK (Dawe *et al*, 2003).

7.3. Water management

In the IGP, water availability for irrigation is decreasing due to more area is coming under rice thus reducing the availability per unit area (Sinha *et al.*, 1998), reduced water supply through canal irrigation, which is linked to less water reserving capacity of the reservoirs due to increasing siltation, and increasing competition for water for domestic and industrial use (Hobbs *et al.*, 1999). Water will become a major constraint to agriculture in the future, as the demand from domestic and industrial use increases and new irrigation facilities are not created. Water shortage is a major constraint to sustaining and increasing the productivity of rice-wheat systems. Reducing seepage, percolation and runoff losses from fields does not essentially save water if it can be recaptured at some other temporal or spatial scale, for example by groundwater pumping, cycling of runoff/seepage water in slopping land at lower elevation. Many technologies like laser leveling, direct drilling, raised beds, non-ponded rice culture and irrigation scheduling appear to save substantial amounts of water through reducing irrigation water requirement, but whether these are true water savings is uncertain as components of the water balance have not been quantified. Reducing non-beneficial evaporation losses is true water saving, and optimal planting time of rice to avoid the period of highest evaporative demand and changing to non-ponded rice culture can save significant amounts of water. Puddling saves water is questionable, however, moving away from puddled, ponded to more aerobic rice culture sometimes brings new production problems. Farmers faced with unreliable water supplies need to store water on their fields as insurance, and puddling assists retention of water during the rice crop.

Low quality waters are frequently used in repeated mode in the IGP. At times they are blended with canal water in water courses to improve the total water supply and also the flow rates. Amalgamation of low and good quality waters have earlier been discouraged because of their adverse effect on crop productivity. However, if the resultant electrical conductivity of the blended water supplies is less than the threshold conductivity, they can be used safely. In combination with new RCTs, blending of water multi-quality water supplies in on-farm water storage reservoirs not only improves the quality of waters having residual sodium carbonates and overcome problems associated with night this water, but can also improve the use of rainwater and water productivity and yields of a bed planted wheat crop. Preliminary results of a trial conducted in Pakistan have been very cheering. Bed planting system also offers scope for use of even the saline waters and in case of saline waters uses in raised bed-furrow land configuration, it permits salt movement to the top of the raised beds keeping the root zone relatively free of salts at the sill and below the furrow. This improves the ability of the plants to avoid early salt injury at seedling stage and subsequently improve salt tolerance of the crop due to crop ontogeny. Bed planting when combined with mulching or residue retention has the potential to reduce evaporation losses from the soil surface, salinization and further improve crop productivity in saline environments (Hobbs and Gupta, 2003). It was also reported that marginal bunds 18-20 centimeter in height around fields could store nearly 90 percent of total rainwater *in situ* for improved growth and production of rice. It was found that these new technologies essentially save water (Hobbs and Gupta, 2003). Zero-tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cutting down on subsequent irrigation; water use is reduced by about 10 cm-hectares. An additional benefit is less waterlogging and yellowing of the wheat plants after the first irrigation that is a common occurrence on normal ploughed land. There is a large gap between water supply and demand under farmers' conventional practices, which needs to be minimized to prevent higher groundwater withdrawals and enhance water use efficiencies. The direct seeding in rice saved about 25% water as compared to conventional method, while water productivity ranged from 0.27 to 0.32 kg/m^3, highest with the direct seeding (Mann, *et al.*, 2004)

7.4. Weed management/ IPM

Weeds are an important component of our agricultural system because of their potential to compete with crops for water, nutrients, air, and light. No other pests have such an association with crops. Weeds are estimated to cause yield losses of 17–47% in transplanted rice, 14–93% in upland rice, and 9–36 % in wheat (Ranjit *et al.* 1988; Ranjit 1981). In the mid-hill area of Kabhre District in Nepal Polygonum *hydropiper* reduced wheat yields by 50% (Harrington *et al.* 1992). Repeated use of isoproturon over the past 16 years in IGP for the control of *Phalaris minor* in wheat has resulted in development of resistance to this herbicide (Malik *et al.*, 1998). To overcome this problem, rotation of herbicides (clodinafop, fenoxaprop, sulfosulfuron, tralkoxydim) and crops has been recommended. In addition, the zero-tillage system has led to reduced weed population pressure in the short term. When practiced in conjunction with one of the newer herbicides, effective weed control is achieved at a much lower rate, especially when closer row spacing (15 cm in place of 22.5 cm) is adopted. Ranjit, (1998) observed from a diagnostic survey made in Naldung area of Nepal on weed management in rice and wheat shows that chemical weed control using 2, 4-D sodium salt raised wheat yields by 30-39% compared to no weeding (farmers' practice).

Balanced doses of NPK fertilizer resulted in a lower incidence of blast and sheath blight diseases compared to the application of nitrogen alone (Shrestha, 1998). A heavy application of compost generally increased blast incidence in general. Two sprays of Validamycin at the rate of 0.2 % during the vegetative and boot stage of the rice crop effectively controlled the sheath blight and increased rice yields at different sites in the river valley of Nepal (Shrestha, 1998). A yield reduction of as much as 26% was observed with a sheath blight severity of 67% (Karki *et al.* 1996). In a diagnostic survey and subsequent soil analysis the predominant fungal species found in the rhizosphere of wheat and rice was *Fusarium* species, *Drechslera rostrata,* and *Penicillium* species. The population of *Fusarium pallidoroseum* was more in conventionally tilled plots compared to zero-tilled. Amongst the fungal genera identified in the rice and wheat rhizosphere, *F. moniliforme*, *F. pallidoroseum*, *D. oryzae* and *D. rostrata* are well known to be pathogenic on paddy, and *Alternaria triticina* and *Bipolaris sorokiniana* are pathogenic on wheat. A little difference was noticed in the incidence and severity of disease between the conventional and zero-till cropping practices. The only noticeable differences were the higher incidence of foot rot, bakanae, and grain discoloration in zero tillage and stem rot in conventionally sown fields (Singh *et al.*, 2002). The effect of cultivation practices on major diseases was characterized at different sites. It was observed that improved practices (planting foundation seed with 120:60:40 kg NPK/ha and weeding) lowered incidence of all major diseases, such as leaf rust, yellow rust, and powdery mildew, at all localities. Compared to farmers' practices (planting farmers' own seed with 8–10 kg NPK/ha and no weeding), the improved practices reduced the incidence of yellow rust by 13–57%, of powdery mildew by 21–31%, and of leaf rust by about 5%. Clearly, yellow rust and powdery mildew can be controlled with better management practices and balanced fertilization (Shrestha,1998). Gyawali *et al.*(1998) stated that Pire (*Polygonum hydropiper* L.), a weed of the wheat crop, is a increasing risk to the rice–wheat system but same time Pire (*P. hydropiper*) and Dampate (*Thalictrum foliolusum)* are potential sources of pesticidal properties that could be utilized against stored grain pests, along with other plant material such as Bakaino (*Melia azedrach*), Ashuro (*Adhqutoda vasica*), Tetepati (*Artemisia vulgaris*), finger millet (*Eleusine coracana*), Shimali (*Vitex negundo* L.), and soybeans (*Glycine mac).* Rice-Wheat cropping system is blessed with the rich nutrient source of straw and stubble. Its incorporation by following *zero-tillage* practice and need based addition of FYM will help in maintaining soil quality and in checking pest and disease attack including rice stem borers.

Plant parasitic nematodes, also known as hidden enemies of plants, often evident easily misdiagnosed symptoms. These tiny organisms are cropping system pests, rather than single crop pests, particularly in the sub-tropical to tropical environments like IGP where cropping intensity is high and conditions favorable for large population buildup. Parasitic nematodes have the potential to seriously reduce the crop growth and yield in a wide range of crop plants. For evidence several farmers in the eastern parts of the IGP, in the state of Bihar, had to burn their wheat crops due to a nematode causing ear cockle disease. The population densities of nematodes monitored in different cropping sequences revealed that rice-wheat-green manure (*Sesbania aculeata*) cropping system was most favorable for population enhancement of *Meloidogyne incognita*, rice-chickpea for *H. oryzae*, and rice-berseem for *Tylenchorhynchus persicus* (Sakhuja *et al.*, 2000).

7.5. Crop rotations/associations

It has been suggested that if these systems could be appropriately diversified, especially with legumes, the systems' sustainability could be enhanced and the process of land degradation reversed (Joshi 1998 and Ali *et al.* 2000). In particular, legumes have potential to make substantial contributions to the nitrogen (N) economy, ability to extract nutrients from deep soil layers (Chauhan 1993), utilize insoluble or fixed P and make it available to succeeding crops (Ae *et al.* 1990), and improve physico-chemical properties of saline–alkali soils (Dhawan 1958). The ameliorative effects of legumes in the cropping systems are well known to farmers in the region, but legumes are relegated to marginal lands because of low profitability and high risks compared to rice and wheat (Joshi *et al.* 2000). During the last three decades, rice and wheat have replaced legumes in nearly 3 million ha area in the IGP (Kumar *et al.* 1999). Most traditional cultivars and land races of legumes take a long time to mature, and are unable to fit into rotation with either rice or wheat. Development of high yielding short-duration cultivars of legumes has, however, created a fresh opportunity for the greater inclusion of legumes in the rice-wheat system. Such cultivars can be grown either as catch crop in rice-wheat (e.g., with Mungbean and black gram, or in rotation with rice e.g., with chickpea or wheat e.g., with Pigeonpea). Pigeonpea is one such legume in which breeding of high yielding short-duration cultivars has been highly successful (Singh 1996). Short-duration Pigeonpea (SDP) cultivars have permitted establishment of a new Pigeonpea-wheat cropping system in the northwest IGP. However, because wheat sowing is often delayed in this crop rotation, development of extra-short-duration Pigeonpea (ESDP) cultivars that will mature 10-15 days earlier than SDP cultivars has received attention (Singh *et al.* 1987). Pigeonpea is a rainy season crop, which requires little input of fertilizer, and due to its deep root system thrives well even under limited rainfall situations. It can provide considerable residual benefit for the succeeding crops such as wheat (Johansen *et al.* 1990). The crop has been traditionally grown as an intercrop or mixed crop with a number of cereals such as sorghum, pearl millet, and maize when sown at the beginning of rainy seasons. Pigeonpea-wheat rotation is a relatively new production system replacing rice or other rainy season cereals with Pigeonpea. Higher price for grains, less water requirement, usable as fuel-wood ability to improve soil fertility are the primary reasons why pigeonpea has been considered a remunerative break (diversification) crop for rice-wheat systems. According to the researchers in the eastern IGP, where the production systems are essentially rice-based, intensification and diversification in the winter (non-monsoon) season is needed to enhance economic viability. Inclusion of Mungbean on raised bed after wheat in R-W system gave an average yield advantage of 0.8-1.0 t /ha, besides improving soil health. Approximately 25 ha area in Eastern IGP (Ballia ,Ghazipur & Mau districts of Eastern UP) was planted with Mungbean after wheat in R-W cropping system by zero till and bed planting in farmer's participatory mode. Farmers have shown positive response towards inclusion of Mungbean in R-W cropping systems for system productivity, profitability and sustainability. Apart from these, a lathyrus cultivar 'Ratna' (very low neurotoxin content) was evaluated in zero till/surface seeding in about 5 ha area in Ballia district in view of reducing rice fallow areas as well as for system intensification and diversification. The important crop rotations, which virtually can directly go for permanent bed planting, are Soybean-wheat, Maize-wheat, Pigeon pea-wheat, Maize-vegetable-wheat, Maize-toria/mustard-wheat, Pigeon pea + Mungbean / urdbean -wheat etc. Even direct seeding of rice in some cases produces similar grain yield with earlier maturity.

7.6. Machinery/seed drills and prototypes including harvesters

Combine harvesting of rice leaves anchored stubbles of 30-45 cm height along with loose straw in strips. It is not feasible to decompose this loose residue in 2-4 weeks time before wheat sowing. Seeding of rice/wheat or any other crops in loose residue of rice was major impediment for the good crop establishment. The initial good crop stand ensures the success of any crop to great extent. The recent development in machinery sector is a boon to address the long standing problem of the farmers. The important features of some of the machines are as under.

7.6.1. National Zero-Till Ferti-Seed Drill

To avoid the expenditure on tillage practices for seedbed preparation and facilitating the timely sowing of winter season crops after rice Zero Till Ferti-Seed Drill was developed at G.B. Pant University of Agriculture and Technology; Pant Nagar. This


Rotary Disk Drill

machine enables us to sow directly after paddy harvest without prior seedbed preparation. This saves the diesel, tractor's working time, labour and most important it gives higher yield.

7.6.2. Rotary Disk Drill

High speed rotary coulter disks attached in the front cuts the loose residues to enable the offset type double disks to place seed and fertilizer in the narrow slit made by the coulters. Using the rotary disk planter it is now possible to drop seed though the loose crop residues without removing them and with only minimal soil disturbance. This machine can sow most crops in loose residue and in presence of stubbles / rot stocks of crops such as sugarcane. This machines will enable farmers to reduce the burning of crop residues of rice, wheat and other crops, leading to eco friendly cultivation (Sharma *et al.*, 2005). The other features of the machine like seed and fertilizer metering and delivering system are similar to zero-till fertilizer cum seed drill, which is also capable of seeding in partially burned or 30-35% standing rice residue. The rice straw is very rich in silica, therefore, high quality rotary plates are required to enhance the longevity of the machine. This will enable the farmers to cover more area without much maintenance cost. The machine performance improves when soil is neither too dry nor too wet.


Happy Seeder

7.6.3. Happy Seeder

This machine was developed at PAU, Ludhiana in collaboration with ACIAR/ CSIRO and works on the principle of chopping the paddy straw and putting it back as mulch after seeding. The advantage of this machine over others is that it spreads the paddy straw uniformly. The disadvantage of this machine is that it requires more power as compared to others.

7.6.4. Punch Planter

This machine works on the principle of a dibbler, places one seed at a time into moist zone. This can function for tilled or untilled situations in presence or absence of surface soil covers. This machine can significantly economize the seed rate because of its ability to maintain uniform spacing between seed. The main feature of this machine is that it can reduce the requirement of costly seed by 40-50 %. Probably, this is cheapest and most versatile seeding machine among all the second generation drills, requiring minimal fuel consumption.


Punch Planter

7.6.5. Double Disk Planter

This machine can seed very well under low residue condition or the sugarcane harvested fields. This is simple zero till fertilizer cum seed drill with double disk for cutting the residue lying on the surface. The advantage of this machine was that it could be used in sowing of different crops together.


Double Disk Planter

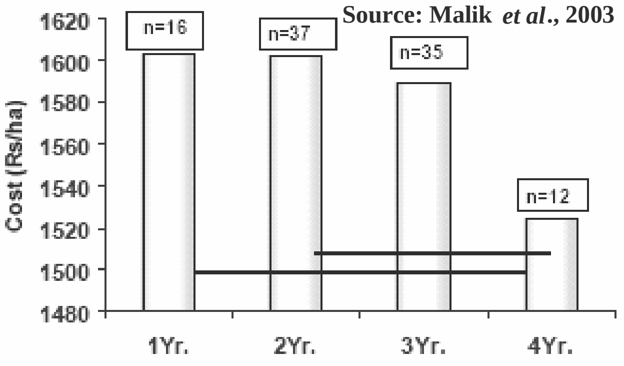
8. Impacts of conservation Agriculture

The adoption of conservation agriculture brings benefits not only to the farm family in terms of increased livelihoods, reduced environmental risk, reduced labor requirements and the possibility of the diversification, but also to other members of society. Downstream water users benefit from decreased sediment load in waterways, and more even stream flow when fed by a greater proportion of ground-water and less surface run-off. Increases in soil organic matter, attributable to the lapse of tillage, surface residue retention and increased biological activity, imply the sequestration of carbon in the soil, and a reduction in carbon dioxide emissions. In broader terms the conservation agriculture could affect the economic, social and environmental scenarios of the region and ultimately it reaches up to global level.

8.1. Economic benefits

Application of herbicides will reduce employment in agriculture for some of the poorest people, including women, who are replacing men in India’s rice fields. Will the gains from herbicide use (reduced labor, timelier weed control, cash-savings for rice producers) outweigh the costs of reduced employment in crop agriculture? Can the rural non-farm sector provide alternative opportunities to earn income? To answer such questions, we must look beyond the use of herbicides by farmers and consider the costs and benefits of herbicides to society as a whole, including gender issues. Under the farmers’ field conditions Malik et al (2003) observed that four year continuous zero-till practice can significantly reduce the investment on weed control (Figure 20). On average, based on many monitored zero-till farmer fields in India, yields of zero-till wheat are from 2-400 kg/ha more (Malik, 2002). At \$100 per ton that works out to \$20-40 per hectare extra income. Gill and Ahmed (2003) in Pakistan showed a 500 kg increase in yield from fields they monitored. Since plowing is dramatically reduced, farmers use 40-60 liters less fuel for land preparation and planting than conventional systems. A farmer’s survey reviled an average saving in land preparation costs of \$36 to \$47 per hectare in Pakistan (Khan and Hashmi, 2003 and Gill and Ahmed, 2003). Zero-till practice also saves 30 % on irrigation and land preparation costs (Aslam et al. 1999).Vincent and Quirke (2002) did a complete economic analysis of the benefits of controlling *Phalaris minor* weeds and use of zero-tillage in Haryana State of India and based on various sources used a figure of \$50 savings per hectare using zero-till. Additional savings are obtained from less pumping or water charges, labor and less wear on equipment. The savings in fuel results in significant reductions in greenhouse gas emissions. In the rice-wheat system, wheat weeds differ from rice weeds and as such zero-till results in less soil disturbance and less (30-60%) wheat weeds germinating (Malik *et al.* 2002). Less water is used for the first irrigation because water flows faster across a zero-till field than a plowed field. Less water is needed in zero-till (15-25%) and bed planting (25-50 %)

Figure 20: Effect of zero-tillage practice on investment on herbicides during the years.



Source: Malik *et al*., 2003

and in fact waterlogging of wheat is not seen after irrigating zero-till and bed planted wheat but is commonly seen in conventionally plowed wheat (Hobbs and Gaunt, 2004). In traditional wheat systems, seed and fertilizer is often broadcast. In zero-till, the drill places the seed and fertilizer in sub-surface bands resulting in better germination and fertilizer efficiency. In bed systems, even topdress nitrogen can be placed in bands and so further improve nutrient efficiency. In RCT's where residues are left in the field, beneficial insects survive better and help reduce pest problems (Jaipal *et al.* 2002). Less lodging in zero-till fields has been also noticed. Sayre and Hobbs (2003) also found that soil organic carbon increases in zero-tilled and bed planted systems especially when residues are left on the surface. It was also noticed that bio-physical properties of surface soil ahs been significantly improved in conservation agriculture fields. It was found that adoption RCTs in India and Pakistan resulted net benefits, of through higher yields and lower land preparation costs, of more than US$150 million in winter 2003 alone. Use of zero-tillage for wheat saves about 50 liters of diesel per hectare, representing a savings of 75 million liters, worth more than US$ 37 million, region wide (RWC-Highlights, 2003-04). Studies in Vietnam indicated the great importance of conservation agriculture in terms of mulching effects on cost of cultivation and finally on agricultural economy. Tam (2004) observed a greater yield with 161 per cent less cost of cultivation due to application of mulch in combination to miniterrace in Vietnam as given in table 10.

Table 10: Effect of mulching on yield and net return.

Treatment	Yield (t/ha)	Total harvest value (1000VND/ha)	Total Expenses (1000VND/ha)	Benefit (1000 VND/ha)	% gain
No miniterrace + no mulch	5.61	10.098	3.085	7.013	100
Miniterrace + no mulch	6.73	12.114	3.885	8.259	11**8**
Miniterrace + mulch	9.08	16.344	5.085	11.259	16**1**

8.2. Social benefits

Recent signs indicate, however, a slow down in productivity growth of the primary cereals, rice and wheat, especially in the intensively rice-wheat cultivated of region IGP in South Asia. Slackening of infrastructure and research investments and reduced policy support partly explain the slow growth. In addition to the, degradation of the lowland resource base due to intensive use, over the long term, also contributes to declining productivity growth rates. Intensification *per se* is not the root cause of lowland resource base degradation, but rather the policy environment that encouraged inappropriate land use and injudicious input use, especially water and chemical fertilizers. Trade policies, output price policies as well as input subsidies have all contributed to the unsustainable use of the lowlands. The dual goals of food self-sufficiency and sustainable resource management are often mutually incompatible.

Policies designed for achieving food self-sufficiency tend to undervalue goods not traded internationally, especially land and labor resources. As a result, food self-sufficiency in countries with an exhausted land frontier, particularly the countries of South Asia, came at a high ecological and environmental cost. Appropriate policy reform, both at the macro as well as at the sector level will go a long way towards arresting and possibly reversing the current degradation trends. It has been noticed that small land holders of eastern IGP (eastern UP, Bihar and Jharkhand states in India) move to northwest part of IGP, particularly Indian Punjab and Haryana, in search of work like harvesting, threshing and transplanting of rice seedling etc to fulfill their family needs. The mechanization of rice and wheat harvesting and threshing decreased their migrations to great extent. Presently, the most difficult work in rice i.e. transplanting of rice seedling in puddled soils, mainly performed by women's of eastern part, is foremost bottleneck in increasing the livelihood of marginal farmers. The second generation development in Resource Conservation Technologies (Rotary Disk Drill, Happy Seeder, Punch Planter, and Double Disk) is a forward step, which will minimize the most arduous task of random rice transplanting in a hot and humid season. This could facilitate the women to put more care to their children and men can choose some other source of income like dairy, poultry, piggery etc. to improve their livelihood. With improved income level they can offer better educate and nutrition to their children. Additionally, the work on direct seeded rice with residue retention will accelerate and uplift of marginal farmers. Besides this, bed planting will provide an opportunity to grow various crops simultaneously or in succession or relays, which further diversify/intensify the cropping system as well as working opportunity. Moreover, intercropping opportunities with bed planting minimizes the risk due to adverse weather condition.

8.3. Environmental benefits

The intensification of rice-wheat rotations has resulted in a more dependence on irrigation, amplified fertilizer usage, and crop residue burning, which all have a direct effect on the variable that most affects global climate change-emissions of greenhouse gases. It has been estimated that the CO_2 equivalent emissions from a high-input, conventionally tilled cropping system with residue burning and organic amendments would equate to 8 Mg C or 29 Mg CO_2 per year if applied to 1 million ha of the Indo-Gangetic plains. In a no-till/residue-retained system, with 50% of the recommended NPK application, the total emissions would equate only to 3.7 Mg C or 14 Mg CO2 per year, an effective halving of emissions as we move from a high to low input system with improved nutrient use and environmental efficiency. The transition to intensified zero-tillage systems, with recommended fertilizer levels, can be both productive and environmentally sound in a world that is rapidly becoming aware of the significant effects of global climate change in both the short and long term. Early results indicate that 1 ha of wheat planted using zero-tillage requires up to 1 million liters less irrigation water than the same crop grown under conventional tillage. Work is underway to determine the overall impact of farm-level savings on command level water demand.

Under RWCs of IGP soil organic matter (SOM) is vulnerable to decomposition it was 5 times more in soils of tropics compared to temperate climate (Matson *et al.* 1997). Analysis of soil samples of farmers' plots of district Ghaziabad has revealed that about 91 % soils are low in soil organic matter (Srivastava 1997). Important reasons of this alarming situation are loss of top soil due to erosion which is accentuated by plowing operation and poor return of organic matter in soil due to practice of burning rice and wheat straw, its removal from field for cattle feed and to paper mill and large scale use of cattle dung as fuel (Srivastava, 2000). Poor soil health adversely affects plant-animal interaction in farming system; poor milk production, prolonged dry period, silent heat, poor conceiving, etc., in cattle were linked to poor feeding status comprising crop foliage, straw and weed flora of nutrients deficient soils of RWCs (Srivastava 1988). Role of soil in ecosystem productivity and health has assumed a new dimension (Harris *et al.* 1996). "Soil quality and health reflect the fitness of a soil body, within land use, landscape and climate boundaries, to protect water and air quality, sustain plant and animal productivity and quality, and promote human health" (Harris and Bezdicek 1994). Harris *et al.* (1996) have conceptualized the importance of soil quality and health vis-a-vis ecosystem health as "healthy soil clean air and water-healthy plants-healthy animal's healthy people." Though little is known about the effect of burning on nutrient loss and dynamics in the rice-wheat system, it has been reported that 40–80% of the wheat crop residue N is lost as ammonia when it is burnt in the field that could be cop up with adoption of conservation tillage practices.

The root reason of soil degradation in sloping lands in Vietnam must be attributed to anthropogenic disturbances for crop production. Mismanagement of sloping lands, leading to severe soil erosion, making soil nutrients exhausted, yet the soil becomes acidic, toxic, compacted, losing water holding capacity, biological activity, etc. that means also losing productivity. As a consequence, the lands become bare, and the area of such bare lands and hills was increased fast in the 1980s. Usually, surface runoff is considered as the most important reason for soil degradation because it causes soil erosion. However, with the new look, it is the kinetic energy of raindrops that cause detachment of soil particles from the bare soil (Greenland, 1989) and then these particles are washed off by the runoff. This way of argument makes us to think about the important role of soil cover in stopping soil erosion. So, the most important reason is the land cleaning, and the runoff is only the secondary reason. The adoption of conservation like mulching terrace making, crop diversification can make this system more sustainable in long term. It can be seen in the Table 11 the conservation agriculture including mulching and growing cover crops in Vietnam resulted in reduction in bare land surface during recent past (Vu Tien Hinh, 2003).

Table 11: Effect of conservation agriculture in Vietnam on change in area of bare lands in hills.

Year	Area of bare lands in hills (1000 ha)	Percentage to total natural area (%)
2003	8,390.5	25.50
1999	10,027	30.5
1995	11,638	35.3
1990	11,768	35.7
1985	11,051	33.6
1980	10,035	30.5
1976	9,774	29.6
1943	6,643	20.0

9. Strategic conceptual issues

9.1. Residue Incorporation vs. retention

Residue incorporation in the rice-wheat cropping system is not very much useful in the IGP because it will require at least some tillage operation. The major problem in this region is optimal sowing time of wheat after rice which is again questionable in case of residue incorporation. If we think about cropping system's diversification, without rice/wheat, the availability of residue will be the problem. So it seems better that residue retention will be the useful technology for R-W system in IGP. Residue retention will not only suppress the weed emergence, conserve soil moisture but also regulate soil temperature which is a critical factor for seed germination of winter crop.

9.2. Fodders for livestock vs. for soil cover

The straw collected from the fields is of great economic value as livestock feed, fuel and industrial raw material. In northern India, wheat straw is preferred while in South India rice straw is fed to livestock (Thakur, 2003). So rice straw could be used as soil cover for 10-20 days and thereafter it could be used as cattle feed the region. Under the present circumstances the residue of rice and part of wheat and sugarcane are available for the conservation agriculture practices. It is estimated that rice alone contributes approximately 120 million tones residue out of total 350 million tones produced in the country (Sarkar *et al.*, 1999). These residues are mainly confined in north western part of the IGP where the cattle population is lesser as compared to eastern part of IGP. It is interesting to note that the cattle and buffalo population (14.39 million) of Punjab and Haryana together is almost one third of UP (44.54 million in 1987). This shows that there is not much conflict for the usage of residues towards conservation agriculture in north western part of IGP. Therefore, under irrigated rice-wheat system of northwest part, the conflict of residue does not arise. Under irrigated conditions, the co-culturing of live mulch like rice+*Sesbania* or Sugarcane+Methi could be a viable options. The apprehension is only in rainfed and regions where cattle populations are more and availability cultivable land is less.

9.3. Need for New cultivars, (G x T) interactions for weed management in CA

In most of the agronomic research programme there is lack of interaction study with respect to genotype to exploit the full potential of any cultivar. It is generally believed that a cultivar performing better at high fertility condition or adequate irrigation or in fine tilth soil will also do better in the just opposite situations i.e. low fertility/ rainfed / no till situations. In the altered tillage scenario like bed planting it was observed that there is interaction between the genotype and planting method for the yield as well as other yield attributing parameters (Sayre and Moreno Ramos, 1997). The wheat crop planted on beds produces bolder grain resulting higher thousand grain weight with minor lodging. Therefore, there is need to develop new plant type for the new tillage system in wheat or aerobic rice cultivar to harness the potential yield in a system perspective. Bed planting reduces lodging owing to lesser water contact on wheat culm and at the same time furrow providing easy movement of air. This planting method also reduces the population of *Phalaris minor* on the top of bed probably due to faster drying and lesser soil moisture compared to furrows. It also provides an opportunity of mechanical weeding in furrows and on the top of beds, if two rows are grown, at an early stage of the crop. At later stages, if weeds are still left then manual weeding is also easy. In case of conservation agriculture either under flat planting or bed planting the weed problem will solved to great extent thereby providing eco friendly cultivation.

10. Policy Implications for CA

Green Revolution" technologies helped turn away food shortages in South Asia. However, they didn't reduce poverty as much as anticipated and today many people still remain hungry and poor due to lack of purchasing power. Future focus is needed to address issues of poverty as well as production gains to match population growth. These will have to come from pioneering yield enhancing technology that improves farmer livelihoods, uses natural resources efficiently and minimizes environmental degradation. An expanded set of stakeholders working in innovative alliances will be needed for extending complex conservation agriculture technology to this bypassed group of farmers. There is a strong need of suitable policy focused on trading of agricultural commodities under global market. After the globalization of agriculture sector the major emphasis is on quality of the produce but same time quantity aspect is also important to feed the generation. However, there is a complex relationship between investment in agriculture, increases in production and productivity, and levels of rural poverty. An increase in agricultural output can lead to a reduction in poverty; a 1% increase in total factor productivity (TFP) lessens the proportion of the population living on less than $1 per day by 1.3% (Thirtle *et al.*, 2001). They further suggest that, over the long term that agricultural supply response is not possible at the sector level without growth in productive efficiency as well as output. It was recognized that policy support through targeted subsidies and favorable credit packages is likely to remain very important to maintain low food prices and lower producer risks and sustain investment in farm productivity. However, the best model cannot be supposed to be the current one. Indeed, existing policies may uphold differences in development within the areas covered by the rice-wheat system. The drudgery implications of labor intensive agricultural development policies, needs to analyzed in depth. A peculiarity is needed between drudgery, labor intensive technology and skill intensive activities. Many of the new development interventions regarding small power units and introduction of RCT's, have as a main goal, reduction of drudgery in agricultural and other rural livelihoods activities. In this way mechanization gets people out of the drudgery cycle and helps improve livelihoods rather than perpetuating paucity by promoting labor intensive, poorly paying but back breaking traditional technology.

11. Conclusions

The agriculture IGP is moving from a phase of concerns for self-sufficiency in food production to broader societal goals related to livelihoods, sustainability, environment, resource base enhancement etc. While we have been successful in achieving the goals of self-sufficiency in food production by increasing production and productivity of limited foodgrain crops in irrigated areas, there are increasing concerns of resource degradation, stagnating productivity in the Rice-Wheat cropping system in the last two decades. To answer these concerns efforts over the past decades have led to development and promotion of alternatives to conventional agriculture. Zero-tillage for sowing of wheat is finding rapid acceptance together with alternate land management practices e.g. Bed planting of wheat, laser leveling etc. In this respect various technologies need to be advanced to suit specific situation/cropping system, particularly key will be to adapt zero-tillage/crop residue management in a cropping system/alternate cropping perspective. It will be also important to understand the implications of new technologies over a period of time and the effect on resource use and quality; disease/pests/ecological scenarios, long term changes in soil properties and their management. Most important will be to promote institutional changes which are conducive to achieve need based participation and multidisciplinary approaches to solve the problem. Partnerships with private-public organizations and a shift from few commodities base production paradigm to broader goals related to livelihoods which will ask for a greater role of social scientist to play to understand and include policy perspectives

Vietnamese agriculture has achieve tremendous results in the last decades, but negative impacts of conventional agriculture have been exposed like decline in soil properties, yield limit and decrease, soil degradation, environment degradation, increased natural calamities. These forced to seek alternatives to conventional agriculture. For the irrigated lowlands of Vietnam, crop diversification, conversion of unproductive to high productive patterns, use of hybrid seeds, increase crop seasons by using short duration varieties, relay cropping, proved to be effective measures to increase land and labor productivity. In the uplands, however, there is lot of constraints in very fragile agro-ecological conditions. So, we have to use very careful and comprehensive approaches if sustainability is the main target. Soil mulching is a cost effective and universal method. It helps us solve soil constraints in more sustainable ways. The most important role of the mulch is the complete stop of soil erosion that also means the stop of soil degradation. This helps farmer in setting permanent fields for food production with high and stable yield. With time, the vegetal mulch will decompose releasing necessary nutrients for plant growth and give high yields. Due to high heterogeneity in soil conditions, the yield increase varies widely from 20% to several hundreds percents with the average of 79.4%. So, farmers can reduce their labor because they can reduce cultivated areas can get higher production. The lands freed from food production can be used for other high cash value crops or for planting fruit trees and forest species. Soil much stimulates biological activities in the soil, softening its texture, improving porosity and water holding capacity. Among soil fauna and flora, earth worms play vary important role in improvement of soil fertility. There are useful organisms like nitrogen fixing, phosphate solubilizing and cellulose decomposing organisms. Some fungi can protect the soil from being compacted by formation of micro-aggregates. As a result, the soil becomes very soft, and there is no need for plowing. So, Soil mulch and direct sowing with minimum soil tillage, together with other sustainable sloping land agricultural technologies, will provide basic foundation for sustainable agricultural development in upland regions, not only in Vietnam but in any locality where sloping land agriculture exists.

12. Research Gaps and the Future thrusts

Conservation agriculture must therefore, appear as a major research and development force for contrasting ecoregions. Improvement in quality of resource base is a prerequisite for enhancing production in many resource poor regions. Mulch based technologies in combination with zero-tillage can led to improved capacity of soils to store rainfall, support crop and reduce erosion. There is a need is to identify the hot spots for better scope to make impact and a need for integrating conservation agriculture with agro-forestry system. The above assessment on conservation agriculture revealed that in IGP significant advances in conservation agriculture have been mostly in the resource rich systems. However, resource poor regions offer a wide scope for alternative to conventional agriculture as is manifest from the global experience. It is important to enhance the human resource development which will be “the critical” prerequisite in taking up some of these emerging areas of long term natural resources concern as a way for transition to achieve sustainable agriculture**.**

In Vietnam knowledge and experience of mulch based direct sowing technologies should be shared among countries in the world. But to scaling up these innovations, closer international cooperation should be developed, in which poor countries should be supported.

Regional conservation agriculture networks could be developed regional cooperation in further research and development of sustainable agriculture, especially in mountainous regions.

Based on above description of rice- wheat systems, concerns of farmers and civil societies which need additional research to find out possible disciplinary/ inter-disciplinary solutions have been summarized in the ensuing table. Relative priorities of the concerns have also been indicated here in Table 12.

Table 12. Thematic concerns, possible disciplinary solutions and priorities based on available opportunities and or information.

S.No.	Thematic Area and Problems	Possible solutions and *Research Gaps*	Priority
1.	Delayed crop establishment		
	• Excessive preparatory tillage, Divergent requirements of rice and wheat crops of the cropping system.	• Extend conservation agriculture practices developed for wheat *to rice culture*. Dry seeding of rice in unpuddled flats / raised beds.	***
	• Development of plough pans and combining in moist fields spoils field level, form ruts, and leads to soil compaction.	• Avoid puddling, free wheeling of tractor, promote *residue retention, controlled traffic and narrow wheels and match wheel spacing* of different machines to avoid compaction.	***
	• Pre-germinated weeds before planting of rice/wheat.	• Use herbicides or develop stale-bed technique.	**
	• Excessive soil moisture prevents/ delays seeding or lead to 'Rice-Fallows' .	• Develop agronomic and crop management *practices for surface seeding*/ *Utera* / relay cropping practices.	**
	• Seeding of crops in presence of crop residues require new drills.	• Continue to refine drill prototypes.	*
	• Low plant density reduces rice yields	• Develop transplanting techniques for unpuddled soils or *direct seeding of rice*.	**
	• Seedling emergence a problem in windrows (excessive residue)	• Design spreaders for uniform distribution of residues by combine harvesters.	***
2	Soil fertility and crop nutrition		
	• Non-conjunctive, imbalanced use of chemical fertilizer and of organics & green manures,	• Promote *co-culture of green manure* crops in rice-wheat.	***
	• P fixation and B deficiency in acid soils	• Study *effects of siliceous rice residues on P fixation*, Use B, cultivars to reduced sterility.	***
	• Emerging K deficiency in micaceous soils	• *Slow-down vermicullitization* of biotite micas and use crop residues.	***
	• Negative nutrient balances,	• Rationale fertilizer use, improve fertilizer use efficiency, legumes for recycling of nutrients, develop *cultivars with better root system* and ability to extract nutrients from unavailable forms.	*
	• Mismatch between nutrient demand and	• Study *combining single deep placement* technique with leaf color chart (LCC).	**

	supply, • Decline in soil organic carbon (SOC) content. • Nutritionally poor quality grains, enhance Medicare costs	• Reduce *tillage*, moderate temperature with surface *mulches,* use of FYM and manures, incorporate legumes as *break crops* for surface cover/grains or both. Cultivars with better rooting. • *Fortification* of feeds, fodder and grains. Develop cultivars with *efficient nutrient translocation* systems to increase the fraction of absorbed nutrients in edible portions, improve quality of produce for higher bioavailability.	*** **
3	Water management • Poor crop stand and reduced water use efficiency. Measure efficiencies of new RCT practices at various level. • Receding water tables and unfavorable salt balances. • Poor nutrient-water interactions. • Poor water management practices and use of low quality water. • Temporary waterlogging in early growth stages of crops leads to yellowing and reduces yields. • Paucity of water in peak summers, non-availability of good quality seed of *Sesbania/* GM crops.	• Introduce and train service providers /farmers on precision *land leveling*, eliminate puddling and improve irrigation schedules. • Shift transplanting to middle of June, conserve rainwater and practice surface cover, Breeding cultivars for improved WUE. • Screen cultivars suited for direct seeding and at graded levels of soil fertility, develop lodging resistant cultivars efficient in nutrient use. • Conjunctive *use of low quality* ground waters in different land configurations. Rainwater management, use gypsum. • Improve soil permeability with drainage and gypsum, use additional N, P. Develop wheat cultivars suited to temporary waterlogging. Use 0-till and bed planting. • Develop *co-culturing practices* for rice and wheat season crops. • *Long-term monitoring* of productivity and sustainability of the RWS as they undergo change,	*** ** * * * ***
4.	Crop Diversification for better livelihoods • Substitute rice with ESD Pigeon pea, maize and introduce ESD Mungbean before rice. • Competing end-use of residues for soil cover and animal feed/ fodder. • Substitute wheat with winter QPM maize in eastern IGP for high biomass. Relocate boro rice to irrigated favourable niches for higher incomes. Analysis of policy at state and national level that will provide guiding principle for diversification in the region • Quality seed in crops is a problem in eastern IGP. • Reduce ‘Rice-Fallows’ in flood prone areas. • Information on agronomic, crop management and flood events inadequate for *developing intercropping systems* for flood-prone areas. • Improve productivity of boro rice ’	• Introduce *permanent system of raise bed planting* in (Pigeon pea, QPM maize and mungbean)-wheat. • Study the potential of *dual purpose wheat* in north -west, and of *maize and inter-crops* for fodder and grains in eastern IGP. • *Replace long duration Mahsuri* susceptible to most diseases with s*hort duration DSR rice* for timely planting of (potato + maize systems) or mustard . Develop more innovative cropping systems that include boro rice, winter maize, potato and vegetables in eastern IGP. • Develop s*eed village* for farmer -farmer exchange of seed or encourage enterprising farmers. • Study potential of chickpea, lentil, and other crops in *tal, chaur and diara* lands in eastern IGP. Develop mixed cropping systems to cover risks of recurring floods / droughts. Promote line sowing. • Study effects of spacing and land configuration , crop geometry . Breed shade loving compatible cultivars for crop/ agro-forestry systems . • Improve nursery raising techniques and develop agronomic and crop management package for low	*** ** *** ** *** ** **

	• *Integrate livestock with crop production* and improve productivity of live-stocks. Farmers unwilling to divert land for fodders.	land and irrigated lands. • Prevent residue burning, improve quality of straws, test dual purpose wheat and maize , improve quality of sugarcane tops.	**
5.	Integrated Pest Management		
	• Development of resistance in *Phalaris minor.* Understand the patho-systems (including weeds) leading to better IPM practice. • Intensive land use systems and surface mulches provide niches for pests carry over. • Weed management a problem in inter-crops; Weeds are a major problem of DSR rice • Improve productivity of cotton–wheat system	• Use rotations and replace wheat with mustard, sunflower, berseem etc.. Promote FIRB planting Develop cultivars competitive to weeds. Develop IWM practices for DSR - *use cover crops, glyphosate, and rotate herbicide use* etc. • Introduce *solarisation* and biological control measures, Study longer term consequences of Zero-till and crop residue retention practices. • Test *new molecules for weed management* in systems: (sugarcane+ wheat/ mustard/ chickpea) (Maize+ potato/ boro rice) ;(Maize+beans/peas). • Test new *pre-and post emergence herbicides* molecules for wet and dry conditions and for direct seeded and unpuddled transplanted rice. • Develop a *permanent wide-bed planting* system for conjunctive use of water and reduce costs.,	*** * ** ** **
6.	Environmental Concerns • Rice culture and methane production, crop residue burning excessive tillage, high decomposition rates of organic matter ,	• Improve *soil structure* and moderate temperature effects for improving the carbon accumulation rates. Develop cultivars with better root system, screen rice cultivars for reduced methane transport/ for DSR and use RCT s.	***
7.	Socio-economic and Policy research. • Accelerate the adoption of RCTs • RCTs as new platform for diversification of RWCS.	• Socio economic *analysis of benefits* and studies of constraints to adoption • Monitoring of s*econd-order system constraints,* particularly changing weed composition and biology with use of herbicides. • Develop *knowledge-based system* for targeting the extrapolation domains for the RCT's,. IPM and nutrient management. • *Understand conditions* wherein new RCTs /planting systems *are appropriate.*	** ** ** *

*** low ; ** medium and *** high**

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