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Conservation Agriculture: A new paradigms to increase resource use efficiency

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ABSTRACT

Worldwide, conservation farming systems play a major role in sustainable agricultural production. Even after realizing the full potential of irrigation, a major part of the farming areas of most countries will remain rainfed. Land holdings of the poor, small and marginal farmers are mostly dependent upon rainfall. Common property resources like grazing land, tree lots and village tanks which are the mainstay of the livelihood of the rural landless people are again entirely dependent upon the rainfall of the area. Rainfed areas have, therefore, assumed great importance for adequate and equitable food and livelihood security of the increasing population of the developing countries. Land degradation is another threat to our food and environmental security. Almost 150 million ha land is degraded due to erosion, water-logging and salinization. Tillage practice in modern agriculture of developed countries had most concern to sustain production in conservation of natural resources. Recycling of crop residues, growing crop of high volume biomass, change in cropping pattern, agroforestry, silvipasture are the some of the modules in conservation agriculture (CA). Annually, 400 m ha-m water is available through rainfall, out of which 75 m ha-m water lossed in erosion and courtly facing problem for drinking water, industrial use and very limited water (30%) is available for irrigation. Harvesting of rainwater *in-situ* and collecting through various mechanical measures and use of it for at least one protective irrigation during dry spell needs atmost attention in conservation agriculture. Crop management in changing weather and efficient utilization of bio-diversity to develop ideal plant genotypes for biotic and abiotic stress tolerance is another challenge in CA. CA is environmentally sustainable and generates considerable net social gains to society. Caution must be taken to avoid blanket adoption of just everywhere; it should be site-specific and need based.

Key words : Agro-forestry, Biodiversity, Conservation, Environmental degradation, Tillage

India is endowed with a rich and vast diversity of natural resources, particularly soil, water, weather, multipurpose trees and bio-diversity. To realize the potential of production system on a sustained basis, efficient management of the natural resources is very crucial. With the advent of high-yielding crop varieties and intensive cultivation, the food grain production has increased from 51 million tonnes (m t) in 1950-51 to a record figure of 210 m t during 2007-2008. This impressive achievement has pulled the country in to self-sufficiency for food demand. With adoption of intensive agriculture to meet the varied growing demands for food, fuel, fiber, feed, fertilizer and products in the recent year, the natural resources are however, put under intense strain resulting in fast degradation and lowering of their production efficiency.

The demographic pressure is rapidly mounting on the natural resources. The present population of 1 billion, accounting for about 18 % of Worlds population supported by only on 2.4 % land area, is estimated to become 1.4 billion by 2025 and 1.7 billion by 2050 AD, needing annually about 380 mt and 480 mt food grain respectively (Yadav and Singh, 2000). This scenario along with the increasing industrialization and urbanization will place tremendous strain on the shrinking resources. Unless corrective measures are taken, there will be irreversible damage to the environment and the very resource base.

Among the natural resources, soil is a finite, non-elastic and non-renewable asset. The dwindling per caput availability of land that decreased from 0.5 ha in 1950-1951 to 0.15 ha in 1999-2000 and is likely to reduce further to 0.08 ha in 2020 AD. Approximately 80 % of the total farm holdings fall in the category of small and marginal with an average holding of <1 ha. Research findings have only shown 3-4 fold productivity potential of land even with the currently available technologies. Thus land of properly managed shall not be a serious constraint to feed the population. The country faces a shortage of water, a key input for agricultural production, despite annual average precipitation of 400 m ha-m, due to erratic and uncertain rainfall in terms of both space and time as also of faculty water management. A substantial portion of ground water in arid and semi-arid regions and in some humid coastal areas is of poor quality. The growing quantitative demand for freshwater from other sectors *viz.*, industry, power and household are further curtailing agriculture share. De-

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spite experiencing water scarcity, hazards of its misuse have not received due attention in practice. In areas of fresh water aquifers, there has been excessive with drawl of groundwater. Judicious integration of all the water resources at the farm, system and basin levels and also appropriate methods for safe use of poor quality water including sewage water will be essential for sound irrigation management.

Land degradation is a major threat to our food and environmental security. There is 150 m ha degraded land constituting 45.5% of total geographical area. The area suffering due to water and wind erosion are 109.7 and 11.7 m ha respectively. The area under waterlogging, salinization/alkalization and other problems are 9.0, 9.2 and 10.3 m ha respectively. The widespread erosion in the hilly catchments area is resulting in excessive siltation of multipurpose reservoirs and other water-bodies of the country at rates higher than their designed capacity.

The development of major and medium irrigation works has also caused degradation of large area with the occurrence of water-logging and secondary salinity. About 4.5 m ha area of commands in irrigation is affected by water-logging and salinity. Presently, ground water is used to irrigate almost about 5.5 m tube wells and more than 10 m dug wells. Unfortunately, these advantages have lead to over exploitation of groundwater forcing fall in the groundwater table in most of the areas.

A major factor responsible for the degradation of the natural resources is soil erosion. The accelerated soil erosion has irreversible destroyed some 430 m ha of land area covering 30 % of the present cultivated area in different countries of world. In general soil erosion is more severe in mountainous than undulating areas. The rate of natural erosion for the world is of the order of 1.5 to 7.0 t/ha/year for the mountainous region and 0.1-7 t/ha/year for the undulation plains. If the global warming trends (caused by increases in atmospheric. CO_2, expected to reach 600 ppm by 2070, continues, global erosion rate may increase considerably. Erosion by water is most serious degradation problem in the Indian context. It has been estimated that soil erosion was taking place at an average rate of 16.35 t/ha/year totaling 5,334 m t/year, Nearly 29 % of the total eroded soil was parentally loss to the sea an nearly 10 % was deposited in reservoirs, resulting in the reduction of their storage capacity by 1-2 % annually. The remaining 61 % of the eroded soil was transferred from one place to another. The annual water erosion rate values ranged from <5 t/ha/year to more than 80 t/ha/year.

Conservation agriculture (CA) is concept for resource saving agricultural crop production that strive to achieve acceptable profits together with high and sustainable production levels. While concurrently conserving the environment, CA is based on enhancing natural biological processes above and below ground. Intervention *viz.*, mechanical soil tillage are reduced to an absolute minimum and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere to disrupt the biological processes.

What is conservation agriculture?

Conservation Agriculture (CA) refers to the system of raising crops without tilling the soil while retaining the crop residues on the soil surface. It has the potential to emerge as an effective strategy to the increasing concerns of serious and widespread natural resources' degradation and environmental pollution, which accompanied the adoption and promotion of green revolution technologies. Since the early seventies, CA has emerged as a way of transition to the sustainability of intensive production systems. It permits management of water and soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation like erosion, compaction, aggregate breakdown etc. Unlike the rest of world, in India and in South Asian countries, spread of CA technologies is taking place in the irrigated Indo-Gangetic Plains where rice-wheat cropping dominates.

Need of conservation

Conventional "arable" agriculture is normally based on soil tillage as the main operation. Soil tillage has in the past been associated with increased fertility, which originated from the mineralization of soil nutrients as a consequence of soil tillage. This process in the long-term leads to a reduction of soil organic matter, which not only provides nutrients for the crop, but it is also, above all else, a crucial element for the stabilization of soil structure. Therefore most soils degrade under prolonged intensive arable agriculture. This structural degradation of the soils results in the formation of crust and compaction and leads in the use of certain implements like ploughs, disk harrows and rotary cultivators have particularly detrimental effects on soil structure. Excessive tillage of soils may result in short-tem increases in fertility, but will degrade soils in the medium-term, structural degradation, loss of organic matter, erosion and falling diversity are all to be expected. Soil erosion resulting from soil tillage has forced us to look for alternatives and to reverse the process of soil degradation.

Runoff and erosion is primarily determined by the degree of land slope in addition to rainfall intensity, vegetation cover, and soil type. The increased in land slopes from 0.5 to 9.0% resulted in to runoff of 109.8 mm to 276.1

mm and the soil loss of 4.10 to 28.2 t/ha (Table 1). The nutrient loss of N 12.2 to 34.9 kg/ha, available P loosed from 0.5 to 1.6 and available K from 6.6 to 16.7 kg/ha (Table 1). This indicates that land slopes while cultivating the field should be maintained less than 0.5% slope.

The increased land slope may be detrimental not only to soil and nutrient loss but it reduced the soil moisture storage capacity of soil and as such due to loss in nutrient and limited soil moisture, it finally reflected on yield as indicated in Table 2. The yield loss of maize and wheat was noticed to the extent of 151 and 1310 kg/ha respectively, when slope was extended from 0.5 to 9.0% (Sewaram and Khola, 2000).

Principles of Conservation Agriculture

Conservation Agriculture is characterized by three principles, which are linked to each other, namely: (i) continuous minimum mechanical soil disturbance; (ii) permanent organic soil cover; and (iii) diversified crop rotations in the case of annual crops or plant associations in case of perennial crops. Following measures are included in conservation agriculture.

Mechanical measures

Mechanical measures being adopted looking to slope of land like contour bunding, are recommended to reduce length and degree of slope. If the slope is <1% and to increase infiltration rate for higher storage of soil moisture, compartmental bunding is preffered in rainfed vertisols (Table 3). The experiment conducted at Kanpur (Table 4) indicated that, among water harvesting and moisture conservation practices, ridge and furrow + vegetative bund (*Leucaena leucocephala*) was found significantly effective in increasing grain yield of maize-mustard sequence and additional net return than contour sowing and other moisture conservation practices. Application of mulching with paddy straw 3 t/ha was also found promising in this crop sequence.

Agronomic measures

The most feasible non-cash measures to increase productivity of crops in Conservation Agriculture are contour farming, strip cropping, close growing crops, vegetative barrier etc. The contour farming is practised when slope is < 1%, which checks the erosion and thus permits more water to infiltrate in lower layer of soil. Strip cropping and vegetative barrier techniques are effective when land slope exceeds 3 %, This technique permit to conserve more water in-situ which will increase availability to crop at source. An experiment conducted at Deharadun indicted that strip cropping reduce soil and water loss which in trun increase the maize and wheat yield at 3:1 and 2:1 proportion compared to cultivated fallow (Table 5) and contour farming. The water and soil loss was 51.8% and 54.08 t/ha in cultivated fallow as against contour sowing and strip cropping. Vegetative barrier is most effective on 2 to 3% slope to check runoff, velocity and reduce length of slope on deep black soil in semi-arid tropics, BBF land layouts is most advantaged to provide drainage and reduce runoff.

Cultural Practices

Besides soil and water conservation, conservation of soil fertility is also important, which is possible through

Table 1. Effect of land slope on runoff (mm), soil (t/ha) and nutrient loss (kg/ha).

Land slope (%)	Runoff	Soil loss	Nutrient loss (t/ha)				
			N	P	K	Ca	Mg
0.5	109.8	4.1	12.2	0.5	6.6	14.0	1.9
2.5	153.5	8.6	25.0	1.1	11.5	16.5	5.4
4.5	208.4	17.7	29.7	1.2	14.9	23.3	7.4
9.0	276.1	28.2	34.9	1.6	16.7	29.7	10.7
CD (P=0.05)	21.8	7.2					

Table 2. Effect of varying land slopes on grain yield (t/ha) of maize and wheat.

Land slopes (%)	Maize grain yield (t/ha)				Wheat grain yield (t/ha)			
	1986	1987	1988	Mean	1986	1987	1988	Mean
0.5	2.178	2.200	2.280	2.219	4.300	4.030	2.500	3.610
2.5	2.350	2.244	2.387	2.337	4.660	3.730	2.030	3.473
4.5	2.261	2.211	2.244	2.239	3.650	3.190	1.310	2.717
9.5	1.668	2.000	2.036	1.968	3.390	2.540	0.970	2.300
CD (P=0.05)			0.216				0.406	

Table 3. Components of conservation agriculture.

Practice	Slope	Topography & Rainfall	Soil type	Purpose
A. Mechanical measurers				
Contour bunding	> 6 %	Flat land with scanty and erratic rainfall	Medium deep black soil	To reduce length and degree of slope.
Graded bund Channel terracing	6 to 10 %	> 800 mm	Red soil and clay soil under less rainfall condition.	To make runoff water trickle rather than to rush out.
Graded border strips	2 to 3 %	High and low rainfall area	Deep red soil	Formed between contour or graded bunds.
Bench terracing	6 to 33 %	Hilly areas with high rainfall		To convert original slope into level field.
Compartmental bunding	< 1%	Rainfed areas	Rainfed vertisols	Storing initial rainfall and permitting increased infiltration rate.
B. Agronomic measures				
Contour farming	< 1%	Rainfed areas		Act miniature barrier to the runoff over soil surface.
Close growing / cover crop	< 1%	Rainfed areas with rainfall of high intensity		Reduce splash erosion and protect soil from beating action of rainfall
Strip-cropping	0.5 to 3 %	Rainfed areas		Check runoff and increase absorption of water.
Vegetative barrier	2 to 3 %	Rainfed areas		Reduce length of slope, check runoff velocity and trap silt.
BBF	< 1%	Semi-arid	Deep black soil	Reduce runoff provide drainage

Table 4. Yield (kg/ha) of maize-mustard and additional net return (Rs/ha) as influenced by *in-situ* moisture conservation and fertilization.

Treatment	Maize		Mustard		Additional net
	1988	1989	1988	1989	return over control
Water harvesting and moisture conservation practices					
Contour sowing (Control)	1,336	1,033	688	752	
Interceptal earth bund	1,360	1,065	943	797	298
Vegetative bund (*Leucaena leucocephala*)	1,406	1,127	923	832	787
Terracing	1,436	1,183	888	848	747
Ridge and furrow	1,540	1,305	1,013	911	1,770
Ridge and furrow + Vegetative bund	1,894	1,687	1,001	974	2,459
CD (P =0.05)	61	123	36	111	
Mulching					
Control	1,422	1,105	790	728	
Paddy straw mulch @ 3 t/ha	1,665	1,363	1,029	976	2,141
CD (P =0.05)	31	58	23	45	

Source: Gupta and Bhan, (1997)

cultural practices and their modifications. Effects of these measures on crop production and soil physical and chemical properties are mentioned below.

Minimum tillage

Minimum tillage is aimed at reducing tillage to the minimum necessary for ensuring a good seed-bed, rapid germination, a satisfactory stand and favorable growing conditions. Tillage can be reduced by omitting operations, which do, not give much benefit when compared with the cost and by combining agricultural operation like seeding and fertilization application. It is practised as: (i) Row zone tillage: After primary tillage, the secondary tillage operation is done in the row zone only; (ii) Plough plant tillage: After the soil is ploughed, a special planter is used and in one run over the field, the row zone is pulverized and seed are sown; (iii) Wheel track planting: Ploughing is done as usual. Tractor is used for sowing and the wheels of the tractor pulverize the row zone.

Table 5. Effect of strip cropping on maize and wheat at 4% slope.

Cropping system	Water loss (%)	Soil loss (kg/ha)	Maize yield (kg/ha)	Wheat yield (kg/ha)
Strip cropping				
3:1	40.7	13.74	2,361	2,935
2:1	37.3	11.29	2,373	2,761
Contour sowing	42.9	20.90	2,107	2,406
Cultivated fallows	51.8	54.08		

Source: Bhardwaj, (1994)

Zero tillage

It is an extreme form of minimum tillage. Primary tillage is completely avoided and secondary tillage is restricted to seedbed preparation in the row zone only.

Direct seeding or planting

Direct seeding involves growing crops without mechanical seedbed preparation and with minimal soil disturbance since the harvest of the previous crop. The term direct seeding is understood in CA systems as synonymous with no-till farming, zero tillage, no-tillage, direct drilling, etc. Planting refers to the precise placing of large seeds (maize and beans for example); whereas seeding usually refers to a continuous flow of seed as in of small cereals (wheat and barley for example). The equipment penetrates the soil cover, opens a seeding slot and places the seed into that slot. The size of the seed slot and the associated movement of soil are to be kept at the absolute minimum possible. Ideally the seed slot is completely covered by mulch again after seeding and no loose soil should be visible on the surface.

Land preparation for seeding or planting under no-tillage involves slashing or rolling the weeds, previous crop residues or cover crops; or spraying herbicides for weed control, and seeding directly through the mulch. Crop residues are retained either completely or to a suitable amount to guarantee the complete soil cover, and fertilizer and amendments are either broadcast on the soil surface or applied during seeding.

No-tillage is now being adopted on more than 95 m ha area world-wide and the technology is showing increasing interest by farmers. The countries with the biggest area under no-tillage are the USA, followed by Brazil, Argentina, Canada, Australia and Paraguay. These are the 6 countries where adoption is above 1 million ha. Approximately 47% of the no-tillage technology is practised in South America, 39% is practised in the United States and Canada, 9% in Australia and about 3.9% in the rest of the world, including Europe, Africa and Asia. (Anonymous, 2008)

Implications and impact of no-tillage technology

World soils are important reservoirs of active carbon (C) and play a major role in the global C cycle. The soil contains two to three times as much C as the atmosphere. In the last 120 years, intensive agriculture has caused a C loss between 30 and 50% and over the past 150 years the amount of CO_2 in the atmosphere has increased by 30% (Reicosky, 2005).

Since the mechanization of agriculture began a few hundred years ago, scientists estimate that some 78 billion tonnes of C once trapped in the soil have been lost to the atmosphere as CO_2 (Lal *et al.*, 2004). This is because, intensive soil tillage accelerates the oxidation of organic matter and converts crop residues into CO_2, which is liberated to the atmosphere contributing to the greenhouse effect and global warming of the planet.

Research performed by the USDA with specialized equipment, shows that soil C is lost very rapidly in the form of CO_2, within minutes after soil preparation and that the amount lost is directly related to the intensity of tillage. After 19 days, the total C loss, from a plot of ploughed-under wheat residues, was up to 5-fold higher than from plots not ploughed. The C loss was equal to the quantity of C in the wheat residues, which had remained in the field from the previous crop. It is the loss of soil C during tillage which reduces soil organic matter content.

Reicosky (1997) reported that average short-term C loss from 4 conservation tillage tools was 31% of the CO_2 from the mould-board plough. The mould-board plough lost 13.8 times more CO_2 as compared to the soil not tilled while conservation tillage tools averaged about 4.3-fold more CO_2 loss. It is estimated that wide dissemination of "Conservation Tillage" (which leaves at least 30% of plant residue cover on the surface of the soil after planting) could offset as much as 16% of worldwide fossil fuel emissions. The wide dissemination of no-tillage technologies would have a greater effect

In the USA, the fate of soil carbon considering 3 hypothesis of adoption of conservation tillage until 2020 was studied. In the first hypothesis, in which conservation tillage adoption rates of 1993 (27%) are maintained, and where conventional tillage prevails, almost 200 m t of carbons are lost to the atmosphere. In the second hypothesis, in which conservation tillage adoption would increase to 57%, a reduction in CO_2 emissions can be observed. In the third hypothesis, when conservation tillage adoption rates would reach 76%, in conventional tillage almost half the carbon is lost in relation to hypothesis one, while Zero Tillage would contribute to increase carbon deposits into the soil by almost 400 million tonnes, where it contributes to increase soil fertility.

In only 15 years, grain production in Brazil more than doubled from 57.8 m t in 1991 to 125 m t in 2004. This increase of grain production matches well with the increase in area under no-tillage. No-till adoption reached about 1 million ha in Brazil in 1991 and then it grew exponentially to 23.6 m ha in 2004. It took about 20 years, from 1972 when the first farmer adopted no-till, to reach one m ha in 1991. In the same period the expansion of cultivated land was only 11% from 37.8 to 42 million ha (Anonymous, 2008).

In 15 years, from 1991 to 2004, no-till adoption in Brazil grew by 23. 6 million ha and grain production increased by 67.2 million tonnes which at average prices of US$ 150/t means additional revenue of about $ 10 billion Dollars. Certainly other factors as improved technology and better varieties, etc., have had an influence in this sharp increase in grain production, but it is probably fair to say that the greatest influence came from applying the no-till technology.

Crop residue

Crop residues are the parts or portion of a plant or crop left in the field after harvest, or that part of the crop that is not used domestically or sold commercially or discarded during processing. CA practices require a critical level of crop residues to maintain or enhance soil chemical, physical and biological properties and prevent land degradation.

The removal of crop residues for or by livestock, either through grazing or cut and carry, is a common practice in most crop-livestock systems. In many cases, residue removal by animals is excessive, leaving insufficient vegetation for soil enhancement and conservation purposes, and compromising the sustainability of the systems.

The crop residue available annually in India is approximately 392.58 mt Out of which 187.48 mt is available for incorporation from which total NPK available for crop is 7.951 mt. Considering available crop residue incorporated propertly, it can replace almost 1.862 mt of nutrients (Table 6).

Effect of adequately managed residues: It adds organic matter, which improves the quality of the seedbed and increases the water infiltration and retention capacity of the soil, fixes carbon by capturing carbon dioxide from the atmosphere and retaining it in the soil, buffers the pH of the soil and facilitates the availability of nutrients, Feeds the carbon cycle of the soil, captures the rainfall and thus increases the soil moisture content, Protects the soil from being eroded and reduces the evaporation of soil moisture.

Badly managed residues: However, provoke an unequal drying of the soil and thus a delay in the warming-up of the seedbed or uneven germination of the crop, interfere with sowing and fertilizing activities and hinder the emergence of seedlings.

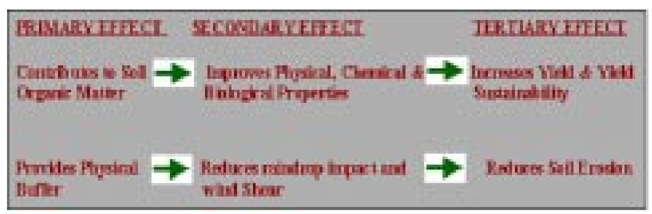

Table 6. Availability and resource benefits of crop residues in India.

Crop	Total crop residues (Mt)	Crop residues available for utilization (Mt)	Nutrient content (% on oven dry basis)			Nutrient potential (Mt)		
			N	P_2O_5	K_2O	Total N+P+K	Available for utilization	Fertilizer replace ment value[4]
Rice	131.70	43.90	0.61	0.18	1.38	2.858	0.953	0.476
Wheat	109.55	36.52	0.48	0.16	1.18	1.994	0.665	0.332
Sorghum	15.30	5.10	0.52	0.23	1.34	0.320	0.107	0.053
Pearl millet	16.22	5.41	0.45	0.16	1.14	0.284	0.095	0.047
Maize	21.21	7.07	0.52	0.18	1.35	0.435	0.145	0.072
Pulses	13.67	4.56	1.29	0.36	1.64	0.450	0.150	0.075
Oilseeds	49.68	49.68	0.80	0.21	0.93	0.964	0.964	0.482
Sugarcane	23.45	23.45	0.40	0.18	1.28	0.436	0.436	0.218
Potato	11.80	11.80	0.52	0.21	1.06	0.211	0.211	0.106
Total	392.58	187.48				7.951	3.724	1.862

1. Total crop residue production calculated by dividing the economic yield by the corresponding economic yield: residue yield ratio
2. Assuming that 2/3rd of the residue is used as feed for animal and other purposes and only 1/3rd is available for utilization except oilseeds, sugarcane and potato residue.
3. Based on residue yield at (2)
4. Based on assumption that half of the total N+P+K is mineralized in a season.

(Anonymous, 2008).

The addition of crop residue in soil before sowing has positive effect on restoration of soil fertility which result in increased yield as indicated in Table 7. The wheat and rice yield increased with pre-crop residues, left over stubble and fly ash application.

The addition of crop residues not only increases the yield but also improves the soil productivity. The organic carbon and, bulk density was increased. The available N, P_2O_5 and K_2O were increased due to addition of crop residues in rice-wheat sequence at Chotha Jammu.

Cover Crops

Keeping the soil covered is a fundamental principle of CA. Crop residues are left on the soil surface, but cover crops may be needed, if the gap is too long between harvesting one crop and establishing the next. Cover crops improve the stability of the CA system, not only on the improvement of soil properties but also for their capacity to promote an increased biodiversity in the agro-ecosystem. In regions where smaller amounts of biomass are produced, *viz.*, semi-arid regions or areas of eroded and degraded soils, cover crops are beneficial.

Vegetative cover is important in CA for the protection of the soil against the impacts of raindrops; to keep the soil-shaded; and maintain the highest possible moisture content. We have seen their importance for nutrient recycling; but they also have a physical and, perhaps, an allelopathic effect on weeds, depressing their incidence and leading to a reduction in agrochemical use and thus in production costs. Straw residues function as a cushion that reduces the pressure on the soil under wheels and hooves and so they play an important role in reducing soil compaction.

There are various crop alternatives to be used as vegetative cover, such as grains, legumes, root crops and oil crops. All of them are of great benefit to the soil, however, some cover crops have certain attributes, which need to be kept in mind when planning a rotation scheme. It is important to start the first years of conservation agriculture with cover crops that leave a lot of residues on the soil surface, which decompose slowly (because of the high C/N ratio). Grasses and cereals are most appropriate for this stage, also because of their aggressive and abundant rooting system, which take less time to improve the soil.

In the following years, when the soil shows a healthier appearance, legume cover crops can be incorporated in the rotation. Leguminous crops enrich the soil with nitrogen and decompose rapidly because of low C:N ratio. Later, when the system is stabilized it is possible to include cover crops with an economic function, like livestock fodder

Crop rotation

The rotation of crops is not only necessary to offer a diverse “diet” to the soil micro-organisms, but as they root at different soil depths, they are capable of exploring different soil layers for nutrients. Nutrients that have been leached to deeper layers and that are no longer available for the commercial crop, can be “recycled” by the crops in rotation. This way the rotation crops function as biological pumps. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna, as the roots excrete different organic substances that attract different types of bacteria and fungi, which in turn, play an important role in the transformation of these substances into plant available nutrients. Crop rotation also has an important phytosanitary function as it prevents the carry over of crop-specific pests and diseases from one crop to the next via crop residues.

Crop rotation showed: (i) Higher diversity in plant production and thus in human and livestock nutrition; (ii) reduction and reduced risk of pest and weed infestations; (iii) greater distribution of channels or biopores created by diverse roots (various forms, sizes and depths); (iv) better distribution of water and nutrients through the soil profile; (v) exploration for nutrients and water of diverse strata of the soil profile by roots of many different plant species resulting in a greater use of the available nutrients

Table 7. Effect of crop residues on grain yield (t/ha) and soil properties of rice-wheat sequence.

Crop residue	Rice yield		Yield of wheat		Organic Carbon (%)	pH	BD (g/cm^3)	Available nutrients (kg/ha)			Microbial Count (x 10^5 cfu/g)
	2001	2002	2001	2002				N	P_2O_5	K_2O	
No crop residue	2.93	3.29	1.87	1.96	0.48	6.6	1.38	185	25.0	170	3.43
Pre-crop residue @ 5 t/ha	3.42	3.68	2.33	2.29	0.65	6.4	1.31	210	36.2	184	5.76
Left-over stubbles	3.12	3.65	2.25	2.21	0.61	6.5	1.35	203	33.0	183	5.42
Fly ash @ 2 t/ha	3.39	3.95	2.37	2.42	0.54	6.4	1.34	204	33.3	176	4.74
CD (P=0.05)	NS	0.31	0.22	0.16	0.10	NS	0.01	12	3.0	6.7	0.29

Source: Kachroo and Dixit, (2005)

and water; (vi) increased nitrogen-fixation through certain plant-soil biota symbionts and improved balance of N : P : K from both organic and mineral sources; and (vii) Increased humus formation.

Effect of preceding crops on succeeding crop

Data presented in Table 8 (Verma, 2001) indicated that mean grain yield of wheat significantly increased when it is preceded with groundnut than rice, however, it was at par with soybean as a preceding crop. However, significantly maximum wheat grain equivalent is obtained with rice as a preceding crop. Incorporation of residue gives significantly highest yield of wheat and wheat grain equivalent.

Intensive technology to increase input use efficiency

Nutrient, water and tillage: the three key inputs interact among themselves synergistically to improve the crop yield and hence the input use efficiency. Tillage practices favorably modify the soil physical and biological environment facilitating root proliferation. These actively growing roots can uptake nutrient and water from a greater soil volume and thus improve the water and nutrient use efficiency. So optimum synergistic combination of water, nutrient and tillage were found for different cropping systems, soil types and agro-climatic regions to improve the overall input use efficiency.

Significant and positive interaction between applied N and water supply was observed on wheat yield and water and nutrient use efficiency by wheat (Table 9). With 80 kg N/ha, N use efficiency increased up to 300 mm water supply in sandy-loam soil. Interestingly, with 120 kg/ha, it did not increase when water supply was increased from 50 mm to 125 mm, but increased markedly when water supply was further increased to 300 mm. This implies that the balance between these two inputs influenced input use efficiency.

Table 9. Nitrogen and irrigation effects on water use efficiency (kg/grain/mm) and nitrogen use efficiency (kg grain/kg fertilizer N) in sandy loam soil.

Irrigation (mm)	WUE N rate (kg/ha)				NUE N rate (kg/ha)		
	0	40	80	120	40	80	120
0	5.3	7.6	8.1	6.0	8.5	5.5	1.5
50	6.3	9.5	11.3	13.3	20.2	18.4	17.8
125	5.7	10.3	11.9	11.8	33.2	25.5	17.0
300	4.6	7.4	9.5	10.2	30.2	30.3	23.7

Post-monsoon rainfed crops, in the absence of presowing irrigation availability, suffer from lack of optimum moisture in the seed-zone depth of germination. Conservation and carry over of seed-zone moisture after withdrawal of rains, through appropriate moisture conservation techniques, helps in timely germination and establishment of post-monsoon rainfed crops in regimes of moderate evaporative demand. Application of wild sage (*Lantana camara*) or eupatorium *(Eupatorium adenophorum)* to previous standing maize (*Zea mays* Linn.) as mulch at recession of monsoon and incorporation of its material at sowing of rainfed wheat significantly improved the grain yield of wheat over the farmers practice in a silty clay loam soil. Furthermore, conservation tillage to wheat with retention of the material at the surface produced grain yield either equivalent to or greater than incorporation of this material at sowing in conventional tillage practice.

Vegetable crops respond favourably to the efficient management of inputs like water and nutrients. Potato prefers a wet moisture regime, which is conducive not only for adequate water supply but also to keep the soil strength low for better development of tubers. Application of pine needle, a waste from pine forests either brunt to prevent forest fire hazard or remove to allow grass to grow, as mulch @ 10 t/ha at the sowing of potato in a

Table 8. Grain of succeeding wheat crop and wheat grain yield equivalent (q/ha) as affected by residue and nitrogen management to wheat crop in sequence cropping.

Treatment	1997-98	1998-99	1999-2000	Mean
Rainy season crop				
Groundnut	30.60 (62.73)	46.77 (80.30)	54.26 (75.72)	43.88 (76.25)
Soybean	29.68 (52.71)	45.04 (67.08)	53.42 (76.57)	42.70 (65.27)
Rice	29.67 (70.02)	43.35 (82.29)	51.45 (92.18)	41.48 (81.50)
CD (P=0.05)	NS (1.97)	1.50 (3.40)	1.77 (2.13)	1.81 (3.45)
Residue management				
Residue removed	29.50 (61.23)	44.37 (75.57)	51.85 (83.27)	41.90 (73.36)
Residue incorporated	30.47 (62.05)	45.73 (77.54)	54.24 (86.37)	43.48 (75.32)
CD (P=0.05)	NS (NS)	1.23 (NS)	1.45 (1.74)	1.38 (1.54)

*Figures in parenthesis are wheat grain equivalent yield shallow depth silty clay loam at Palampur significantly improved tuber yield and water use efficiency and resulted in saving of 1 irrigation equivalent to 40 mm (Table 10).

Application of pine needle mulch @ 10 t/ha with 60 kg N/ha registered significantly higher tuber yield and water use efficiency over 120 kg N /ha without mulching, indicating saving of 60 kg N /ha through the former treatment. The effect of the pine needle mulch was more conspicuous during the Autumn than in Spring because of relatively favourable weather condition and longer growing period during Spring than in the Autumn season. Thus, application of pine needle mulch proved effective in potato through favourably modifying the soil hydro-thermal regime and saved water and nitrogen consumption without sacrificing crop yield and thereby enhanced water and nitrogen-use efficiency.

Table 10. Tuber yield and water use efficiency (WUE) of potato as influenced by mulching and N application (pooled over 4 years).

Treatments	Autumn potato		Spring potato	
	Yield (t/ha)	WUE (kg/ha-cm)	Yield (t/ha)	WUE (kg/ha-cm)
N 60 kg/ha (N_1)	8.46	479.9	13.30	257.0
N 120 kg/ha (N_2)	9.86	528.2	15.15	271.2
PNM + N_1	12.69	711.0	16.33	340.9
PNM + N_2	14.52	735.5	18.34	395.4
CD (P=0.05)	1.19		1.46	

*PNM: Pine needle mulch @ 10 t/ha

Enhancing the water-use efficiency of crops

Water-use- efficiency by crops can be improved by selection of crops and cropping systems based on available water supplies and increasing seasonal evapotranspiration (E.T). The later can be achieved by selection of irrigation method, irrigation scheduling, tillage, mulching and fertilization

Selection of crops and cropping system

Selection of crops and cropping systems for high water-use efficiency should be done on the basis of availability of water under rainfed crops, limited irrigated crops, and fully irrigated crops.

Rainfed crops

The amount of rainfall converted into plant-available soil-water is determined by the amount and intensity of rainfall, topography, infiltrability and water retentivity of soil, depth of root zone and soil depth. Depth of soil due to its effect on the available water storage capacity decides the type of cropping system that can be followed in a locality. In the shallow vertisols of Indore region with 100 mm of available water only monocropping of sorghum or Corn can be practised. On medium soil depth monocropping or intercropping can be practised whereas in deep soil with 200 mm available soil moisture status double cropping can be practised.

Limited irrigated crops

Selection of crops and cropping sequences under limited irrigation situation should be done as there should be minimum water stress during the growing season although some water-stress to the crops and associated yield reduction is inevitable. Therefore, along with selection of crops special care should be taken for irrigation scheduling of these crops.

Fully irrigated crops

Under this condition selection of crops is not- constrained by water availability but by adoptability of the crops to prevailing climatic and soil condition. In general, C^4 plants have potential for greater water use efficiency than C^3 plants, particularly under semi-arid environment.

Tillage

Conservation tillage practice normally stores more plant available moisture than the conventional inversion tillage practices when other factor are same. The high soil moisture content under conservation tillage is due to both improved soil structure and decrease in the evaporation loss due to crop residue mulch cover. Increase in the available water content under conservation tillage, particularly in the surface horizon, increases the consumptive use of water by crops and hence improves the water use efficiency.

Mulching

Mulching influences water use efficiency of crops by affecting the hydrothermal regime of soil, which may enhances root and shoot growth, besides it helps in reducing the evaporation (E) component of the evapotranspiration. Under moisture stress conditions, when moisture can be carried over for a short time or can be conserved for a subsequent crop, mulching can be beneficial in realizing better crop yield. .

Fertilization

There is strong interaction between fertilizer rates and irrigation levels for crop yield and water-use efficiency. Application of nutrients facilitates root growth, which can extract soil moisture from deeper layers. Further more, application of fertilizers facilitates early development of canopy that covers the soil and intercepts more solar radiation and, thereby, reduces the evaporation component of the evapotranspiration.

Efficient nutrient management

Nutrients play key role in increasing agricultural production through intensive cropping. Sustainable agriculture can be achieved by efficient utilization of this costly input. Nutrient use efficiency can be improved by checking the path ways of nutrient losses from soil-plant system, making integrated use of nutrients from all possible sources, optimal allocation of nutrients to crops and maximizing the utilization of applied and native nutrients by the crops.

Checking the pathways of nutrient losses

Nutrients present in soil and added through fertilizers and manures are lost by gaseous loss, leaching loss, runoff/erosion losses and fixation in soil. Efficient nutrient management demands understanding the pathways of nutrient losses and developing technologies to minimize these losses.

Part of the applied N is lost from soil by volatilization of ammonia and part of the nitrogen is lost as N_2O and N_2 gas by denitrification. Volatilization loss of ammonia can be minimized by mixing of nitrogen fertilizers in soil rather than broadcasting on soil surface, deep placement of urea super granules (USG) in puddled rice field, using urease inhibitors like thiourea, methyl urea, caprylohydroxamic acid, phenyl phosphorodiamidate (PPD), ammonium thiosulphate (ATS) etc. and adding inorganic salts of Ca, Mg or K with urea. Some coated materials like sulphur coated urea (SCU), gypsum coated urea (GCU), plastic coated urea (PCU), mud ball urea and synthetic slow release urea based fertilizers *viz*., isobutylidene diurea (IBDU) and crotonylidene diurea (CDU) etc. may be used to retard the rate of urea hydrolysis and thereby, reducing ammonia volatilization.

Nitrous oxide (N_2O) is mainly produced by denitrification of NO_3 under anaerobic condition, as in low-land rice fields. Nitrous oxide is one of the greenhouse gases that is believed to be forcing global climate change. Denitrification loss can be minimized by avoiding the use of NO_3^- form of nitrogenous fertilizer (*e.g.* calcium ammonium nitrate, potassium nitrate etc.) in rice and use of nitrification inhibitors *viz.*, Dicyandiamide (DCD), N-serve (2-Chloro, 6-tri-chloro methyl pyridine), AM (2-Amino, 4-Chloro, 6-methyl pyrimidine), coated calcium carbide (CCC), neem coated urea, deep placement of urea super granules (USG) in flooded rice field and efficient water management.

Mobile nutrients (*eg.* $N0_3^-$) are lost from the soil-plant system with the percolating water. Besides reducing the nutrient use efficiency these nutrients may pollute the groundwater. The groundwater having more than 10 mg NO^3, N/liter is unfit for drinking purpose (WHO). Leaching loss of NO_3^- can be minimized by balanced fertilization, split application of urea synchronizing with crop demand, manipulation of water application and rooting depth, appropriate crop rotations and use of slow release fertilizers and nitrification inhibitors like N-serve, DCD, AM, CCC and neem-coated urea. Despite the success of synthetic nitrification and urease inhibitors in research farms, they have poor acceptability among farmers because of high cost. However, the use of products and byproducts of locally available plants like neem for coating urea can be popularized among the farmers to effect N economy and minimize long term environmental consequences of denitrification and nitrate leaching.

Many water-soluble nutrients are lost through runoff. This loss can be minimized by proper land management and selection of proper crops and cropping systems, tillage and mulching. Nutrients sorbed on the surface of soil particles-clays and silts and soil organic matter are lost when the top soil is eroded by water or wind. Proper soil conservation measures should be adopted to minimize this loss.

In acid soils phosphorus is fixed as FeH and AH phosphates and in neutral and calcareous soils it gets fixed as CaH phosphate. The availability of these fixed phosphates is low. Phosphate-fixation in acid soil can be reduced by combined application of rock phosphate and single super

Table 11. Research studies carried out at various research centers on different aspects of fertigation by using drip irrigation.

Crop	Location	Fertilizer used	Saving in fertilizer (%)	Yield advantage (%)	Cost economics
Tomato	MPAU, Rahuri	9:8:8, 12:0:12	25	24	
Orange	PKV, Akola	6:12:6		50	Highest B : C ratio
Grapes	Jain R D farm, Jalgaon	19:19:19, 13:0:46	25	29	27% increase in market realization
Grapes	UAS, Bangalore	18:44:0, 16:8:24	20	37	B:C ratio 3.20:1
Sapota	UAS, Bangalore	19:19:19	20	74	Higher market realization
Potato	UAS, Bangalore	19:19:19	20	22	Highest realization and returns (80%)
Broccoli	WTC, Delhi	88:8:	20-40		CBR 2:1
Onion	Jain R D farm, Jalgaon				

phosphate and liming of acid soils. In both acid and calcareous soils phosphorus-fixation can be minimized by band placement of phosphatic fertilizers along with crop rows. Use of rock phosphate along with acid forming materials like pyrites or phosphate - solubilizing micro-organisms help in solubilization of sparingly soluble rocks. Vescicular -arbuscular mycorrhizal (VAM) fungi are helpful in mobilizing both applied and native reserves.

KH^{++} and NH_4^{++} ions are also fixed in the inter-layer of 2:1 clay minerals like illite, vermiculite etc. Nutrients fixed on soil are not exactly lost from the soil-plant system but are not available to the crop in a short-term period. However, these are released at later stage of crop growth.

Application irrigation and nutrient in conjunction through pressure irrigation system result in efficient utilization of both resources. This will save water as well as reduces nutrient leaching losses and thereby increased WUE as well as NUE. This will increase the yield and quality of crops. There is saving of water and nutrient to the extent of 35 and 22 %, respectively. Fertigation is most commonly used for plantation crops like banana, sugarcane, and orchards of Maharashtra.

The research carried out throughout the country indicated 20 – 40% saving in fertilizer (Table 11) and yield advantages to the extent of 74% in Sapota at Bangalore. This technology is to be propagate extensively on farmers field by motivating the illite and marginal farmers (Singh and Gautam, 2002).

It is concluded that conservation Agriculture practices result in resource improvement only gradually and benefit in crop yields may not come about immediately, evaluation and impact of CA practices therefore needs a longer-term and a broader perspective which goes beyond yield increases only. From the economic analysis it is concluded that “no-till and crop rotations constitute a technological revolution for small farmers. Conservation agriculture is environmentally sustainable and generates considerable net social gains to society. Caution must be taken to avoid blanket adoption of CA just everywhere; it should be site-specific and need based.

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