Review Article

CONSERVATION AGRICULTURE AND CROP RESIDUE MANAGEMENT

Abstract

India being a populous country the intensification of the cropping system is mandatory. However, this intensification of the cropping system results in the degradation of soil and other natural resources. Considering this situation, conservation agriculture is the most suitable alternative to achieving sustainable yield and productivity. Conservation agriculture is based on three major principles those are minimum disturbance of soil, crop rotation, and maintenance of crop residue. Crop residue management plays a major role in conservation agriculture as it helps in improving soil productivity, soil organic matter content, soil structure, soil water conservation, air quality, and reduction in soil erosion. India produces 273 Mt of crop residues annually which contain a total of 7.16 Mt of nutrients (N-1.28, P_2O_5-1.97, K_2O-3.91). In modern agriculture, green manure crops like *Sesbania* and sunhemp increase the quantity and quality of the crop residues in the crop field. Among various residue management practices mulching has been practiced prominently in dry lands as it increases the resource use efficiency. The residue decomposition is affected by various factors like quality of crop residue, edaphic, management, and climatic factors. In modern scientific research crop residues are being used especially for site-specific nutrient management. It is observed in most studies that zero tillage or reduced tillage with crop residue gives comparatively higher net returns, water use efficiency, and resource use efficiency than conventional agriculture.

Key words: Conservation Agriculture, Residue management,

Introduction :

Throughout the world, conserving natural resources is crucial due to intensive soil cultivation, which globally degrades agricultural soils by reducing organic matter and soil structure (Pingali et al, 2004). To ensure good crop yields and resource efficiency, manipulating the soil-water-plant environment system is essential. Conservation agriculture (CA) is relevant for restoring degraded ecologies and addressing concerns about farm income and declining yields. Indian agriculture is now entering a new phase, responding positively to growing concerns for sustainable agriculture through the advancement of conservation agriculture as a new paradigm for sustained agricultural production.

A high level of organic matter for higher crop production is a must in any ecology, but most of the organic tropical soil containing about 0.5 to 2% organic matter in the soil is getting depleted more over the years. Soil organic matter (SOM) facilitates the aggregation and structural stability of soils which are responsible for air-water relationship for root growth and protection of soil from wind and water erosion. Given the high cost of inorganic fertilizers and the gap between nutrient addition and removal, recycling available organic matter is necessary. Sustainable agriculture should typically be based on Integrated Plant Nutrition Supply (IPNS) systems, combining chemical fertilizers, organic wastes, and bio-fertilizers to improve crop productivity and soil health. Crop residues are a tremendous natural resource, not waste materials that require disposal. It is the primary source of carbon inputs and the ways in which these are managed have a significant effect on soil physical, chemical, and biological properties (Kumar and Goh, 2000). These are good source of plant nutrients and are important components for the stability of the agricultural ecosystems. About 25% of N and P each and 50% of S and 75% K uptake by cereal crops are retained in the crop residues, making them valuable nutrient sources. Organic matter resulting from the decomposition of crop residues comprises various complex compounds. Unlike chemical fertilizers, organic materials have a lower nutrient concentration and are needed in larger quantities in the field. They contain nutrients like nitrogen, phosphorus, potassium (NPK), and micronutrients in smaller amounts, while organic matter itself is present in larger quantities. Organic matter has very low salt index compared with some chemical fertilizers like Ammonium sulphate or CAN containing more amount of salts. The N and K fertilizers have a very high salt index. The salt index is expressed by the following formula:

$$\text{Salt Index} = \frac{\text{Increase in osmotic potential of the soil due to added materials}}{\text{Osmotic potential produced by the same mass of Na }(NO_3)_2}$$

Over the last three decades, there's been a surge in global research and adoption of RCTs like zero and reduced tillage systems, along with better crop residue and planting management, all geared towards conserving nutrients and water. The goal? To ramp up productivity while safeguarding our natural resources and the environment. Conservation agriculture is currently practiced in more than 106 million ha worldwide in more than 50 countries and the area is expanding rapidly (Rattan *et al*., 1996). This chapter not only delves into the detailed research findings on residue recycling, a common practice within conservation agriculture but also explores various conservation agricultural practices, perspectives on residue management, their principles, methods, and the potential advantages and disadvantages. This provides a holistic view of conservation agriculture and crop residue management.

Hence, the terms ‘Conservation agriculture’ and ‘Resource conserving techniques’ (RCTs) are used interchangeably. RCTs encompass practices that improve resource or input-use efficiency, such as saving water, nutrients, herbicides, and energy through methods like zero tillage. Generally, conservation agriculture practices include:

- Maintaining soil cover, especially by retaining crop residues on the soil surface
- Implementing sensible, profitable crop rotations
- Minimizing soil disturbance, such as through reduced or zero tillage.

The major differences among the various tillage practices have been given in Table 1.

Table 1. A comparison of Traditional tillage (TT), conservation tillage (CT) and conservation agriculture (CA) for various issues

Issues	Traditional tillage (TT)	Conservation tillage (CT)	Conservation agriculture (CA)

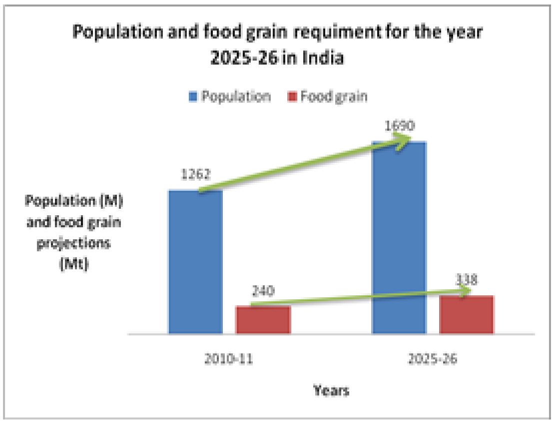
Practice	Disturbs the soil and leaves a bare surface	Reduces the soil disturbance in TT and keeps the soil covered	Minimum soil disturbance and soil surface permanently covered
Erosion	Wind and soil erosion maximum	Reduced significantly	The least of the three
Soil physical health	The lowest of the three	Significantly improved	Significantly improved
Compaction	Used to reduce compaction and can also induce it by destroying biological pores	Reduced tillage is used to reduce compaction	Compaction can be a problem but use of mulch and promotion of biological tillage helps reduce this problem
Soil biological health	The lowest of the three owing to frequent disturbance	Moderately better soil biological health	More diverse and healthy biological properties and populations
Water infiltration	Lowest after soil pores clogged	Good water infiltration	Best water infiltration
Soil organic matter	Oxidizes soil organic matter and causes its loss	Soil organic build-up possible in the surface layers	Soil organic build-up in the surface layers even better than CT
Weeds	Control weeds and also causes more weed seed to germinate	Reduced tillage control weeds and also exposes other weed seeds for germination	Weeds are problem especially in the early stage of adoption
Soil temperature	Surface soil temperature More variable	Intermediate in variability	Moderated the most
Diesel cost	Diesel use: High	Intermediate	Much reduced
Production cost	Highest	Intermediate	lowest
Yield	Can be lower where planting delayed	Yields same as TT	Yields are the same as TT but can be higher if planting is done timelier.

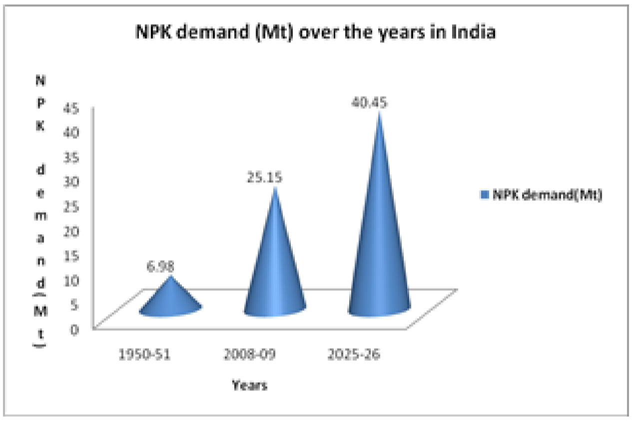
Source: Hobbs *et al.* (2008)

2. NUTRIENT POTENTIAL OF VARIOUS ORGANIC RESIDUES IN INDIA

2.1. Organic residues requirement and potential

Naturally, the maintenance of food and water security for all its people is more arduous than in other countries in India. India harbors 17% of the global population in only 2.3% of land mass supported by 4% of freshwater resources. The population in India during 2010-11 is estimated to be 1262 million (M) and it will be 1690 million in 2025. The demand for food grains would be 240 million tons (Mt) in 2010-11 and it would be 328 Mt by 2025.





Source: Ramakrishna Parama and Biswas (2009)
Fig. 1. A projection on food grain and nutrient requirement in India over the year 2025-26

The consumption of fertilizer nutrients ($N+P_2O_5+K_2O$) in India in the year 1950-51 was 69,800 tonnes which increased to 25.15 million tonnes in 2008-09 (Figure 1). By the year 2025-26, India may need 40-50 million tonnes of fertilizer nutrients. India is the third-largest consumer of fertilizer after China and the US (FAI, 2009). In 1950, organic manures produced almost 98% of India's nutrients, which became 50:50 in the 1970s and is now 25:75. In India, the vertical dimension is the only option where the horizontal dimension is limited, although it is also restricted in the western Indo-Gangetic Plains. In Indian agriculture, organic and inorganic sources are required to meet nutrient needs and increase crop output for the growing population by 2025-26. Table 2 estimates the input and removal of plant nutrients (N+P2O5+K2O) in India from 2000 to 2020. Tapping is possible in 30% of manure, 80% of excreta, and 33% of crop. India utilizes 14 million tons of N (82% Urea), 5.8 million tons of P2O5 (66% DAP), and 1.6 million tons of K20 yearly. In India, roughly 30 million tons of NPK is lost from soil, only 20 million tons of NPK is added and 10 million tons is shortfall. About 5 million ton of soil is washed away every year taking with 6 billion tons of soil nutrients owing to inadequate soil management methods (Sen, 2009).

Table 2. Projected plant nutrients ($N+P_2O_5+K_2O$) addition and removal in India (Mt)

Projected plant nutrients ($N+P_2O_5+K_2O$) addition and removal	Year	
	2000	2020
Addition of nutrients through fertilizer	18.07	29.6
Removal of nutrients by crops	28.0	37.46
Balance	-9.93	-7.86
Total projected availability of plant nutrients from tappable organic sources	5.05	7.75

Sources: Tandon (1997); FAI (2009)

Though the assessment of biomass resources is a herculean job, it reflects the possible availability of organic resources. Various authors have put forth their inventory of organic residues, both of plant and animal origin. The four main areas of organic residues regeneration are agriculture, animal husbandry, agro-industries and urban and rural inhabitation. Projections of tappable nutrients from various organic sources and likely quantities available for recycling have been provided by several authors. Bhardwaj (1995) and Tandon (1997) have provided the details of the crops, animal and human wastes available for recycling and their nutritive values and the extent of residues of major crops in India (Table 3). Introduction of green manure crops like Sesbania and sunhemp in the farm land along or in between the two crops has increased both the quantity and quality of the crop residues in the modern agriculture. The introduction of alien weeds like *Lantana camera* and *Eupatorium adenophorum* and other indigenous vegetative biomass (both facultative and obligate weeds) and forest litters also are using very good source of organic matter and their residues are also commonly used in various parts of the world. The subabul plant *(Leucaena leucocephala)* is gaining importance due to its multiple uses in Indian dry-land farming is also taken as the source of organic residues.

Table 3. Nutrient potentialities of various organic residues in India

Sources of organic resources	Availability (Mt/yr)	Total nutrients (Mt/yr)			
		N	P_2O_5	K_2O	Total
Crop residues	273	1.28	1.97	3.91	7.16
Cattle manure	280	2.81	2.00	2.07	6.88
Rural compost	285	1.43	0.86	1.42	3.71
Forest litter	19	0.10	0.04	0.10	0.24
City garbage	15	0.23	0.15	0.23	0.61
Press mud	3	0.03	0.079	0.055	0.164
Sewage water (million cu m)	6351	0.32	0.14	0.19	0.65
Industrial waste water (million cu m)	66	0.003	0.001	0.001	0.005
Total	-	6.203	5.20	7.976	19.419

Source: Bhardwaj (1995); Tandon (1997)

3. RESIDUE PRODUCTION IN INDIA

3.1. Agricultural crop residues production and use

Understanding the area under agricultural crops, cropping pattern and utilization of crop residues is essential for assessing the availability of crop residues. Out of 329 million hectares (Mha) of total geographical area, the cropped area accounts for about 43%, and the net cultivated area has stabilized around 143 Mha since 1970 in India. However, the gross cropped area has increased from 152.8 Mha in 1960 to about 189.5 Mha in 1996-97 and is likely to be 222 Mha by 2010 (Agricultural Statistics at a Glance, 2001). The gross cropped area includes land areas subjected to multiple cropping, of which net irrigated areas have increased substantially from 24.7 Mha from 1960-61 to 55.1 Mha by 1997-97. Rice and wheat are the dominant crops, accounting for 41 % of the cropped area while pulses, oilseeds, and other commercial crops account for 13.8, 15.9, and 10.2 %, respectively. Cereals dominate the agricultural crops as given in Table 4 (Directory of Indian Agriculture, 1997), and account for the cropped area of 60% of cropped area followed by pulses, cotton, and sugarcane. The further expansion of the irrigated area in India is estimated up to 50-56% by the end of 2010 and that would influence the production of crop residues in the future too.

Table 4. Estimated area under different crops and their respective residue production in India during 2010

Crops	Gross	Total	Total residue	Residue to

	cropped area (M ha)	economic production (Mt)	production (Mt, air residue production (Mt, air dry)	final economic produce ratio
Rice	46.1	118.8	213.9	1.8
Wheat	28.5	98.5	157.6	1.6
Jowar	5.3	6.1	12.2	2.0
Bajra	8.6	6.8	13.6	2.0
Maize	6.6	13.0	32.5	2.5
Other cereals	1.3	1.4	2.8	2.0
Red gram	3.6	2.7	11.2	5.0
Gram	7.7	7.0	13.5	1.6
Other pulses	12.5	5.9	17.1	2.9
Groundnut	9.3	12.2	28.1	2.3
Rapeseed and mustard	10.7	12.0	24.1	2.0
Other oilseeds	18.0	13.5	27.1	2.0
Cotton	10.1	15.9	55.7	3.5
Jute	0.6	6.5	10.5	1.6
Sugarcane	5.5	463.5	185.4	0.4
Coconut + areca nut	2.8	-	28.2	-
Mulberry	0.3	-	3.3	-
Coffee + tea	0.8	1.0	3.9	4.0
Total	**178.2**		**840.7**	

Source: Directory of Indian Agriculture (1997)

The production of residues varies between different types of crops. The data on residue-to-product ratio (RPR), which represents the ratio of residues to the final economic product, can be found in Table 4. The ratio of straw to grain varies among cereals, ranging from 2.5 for maize to 1.6 for wheat. Straw, a low-density residue, is the most abundant. Rice husks, a by-product of rice milling, make up 20% of paddy. Unlike cereals, crops like pigeon pea, cotton, rapeseed, mustard, mulberry, and plantation crops produce woody residues. The use of crop residues also varies by region, depending on factors like caloric values, lignin content, density, palatability, and nutritive values. Most cereals and pulses residues also have fodder value. In India, crop residues are primarily used as fodder for cattle, fuel for cooking, thatch materials for housing, and organic resources. Leguminous crop residues are typically composted after harvest. Rice and sugarcane leafy residues are usually burned or used as fuel. The dominant residues in India come from rice, wheat, sugarcane, and cotton, accounting for 72.9% of total residue production, with sugarcane and cotton producing 185.4 Mt and 55.7 Mt, respectively.

Although fertilization practices have become more important in the rice-wheat cropping system over the last three decades, crop residues still play a crucial role in nutrient cycling. Table 5 provides estimates of directly recyclable rice and wheat residues in different states of the IGP region of India, along with associated nutrient potential. With 37.87 Tg of rice and wheat residues available for recycling, the associated nutrient potential (N + P + K) is 0.634 Tg. The rice-wheat system contributes to about one-fourth of total crop residue production in India (Sarkar et al., 1999). One ton of rice residues contains approximately 6.1 kg N, 0.8 kg P, and 11.4 kg K, while one ton of wheat residues contains 4.8 kg N, 0.7 kg P, and 9.8 kg K.

Table 5. Rice and wheat crop residues are available in different Indo-Gangetic states of India and usable nutrients contained in residues (Tg*)

State	Residues available			Residues available for recycling	Nutrient (N + P + K) potential		
	Rice	Wheat	Total		Total	Available for direct recycling	Fertilizer replacement value
Punjab	10.0	18.2	28.2	9.40	0.462	0.154	0.077
Haryana	2.5	9.7	12.2	4.07	0.194	0.065	0.032
Uttar Pradesh	14.0	27.5	41.5	13.83	0.677	0.226	0.113
Bihar	9.6	5.3	14.9	4.97	0.257	0.086	0.043
West Bengal	16.7	0.1	16.8	5.60	0.308	0.103	0.051
Total	52.8	60.8	113.6	37.87	1.898	0.634	0.316

Note: *1Tg = 10^{12} g Source: Sarkar *et al*. (1999)

3.2. Animal wastes and their potentialities

Animal wastes are one of the major underutilized resources in India and many other countries. The dung and urine along with bedding materials obtained from animals are their major sources of crop residues. India has the world's largest bovine population and recorded 294 million during 1996-97 including cattle, bullocks, buffaloes, and calves with a cattle-to-human ratio of 0.3. Cattle accounts for > 2/3 of the bovine production and buffaloes account for 28.6% (Anonymous, 1997).

Table 6. Livestock population, dung production, and its availability in India

Animals	Year					
	1996-97			2009-10		
	Cattle	Buffalo	Total	Cattle	Buffalo	Total
Population (million)	209	84	294	224	97	321
Dung production (kg/head/day)	4.5	10.2	-	4.8	10.2	-
Total dung produced (Mt/yr)	344	315	659	368	362	730
Dung recoverable (%)	60	80	-	60	80	-
Total dung recoverable (Mt/yr)	206	252	458	221	289	510

Source: Anonymous (1997)

The population of goats and sheep is estimated to be 169 million, and the estimated populations of cattle and buffalo for 2010 are 224 and 97 million, respectively. Interestingly, the piggery and poultry industry has grown substantially in the last 2 decades in an organized way and hence, the manure could be used for nutrient recycling. Based on the mean annual average dung yield (fresh weight) of 4.5 kg/day for cows and 10.2 kg/day for buffalo, total dung production is estimated at 659 Mt annually, with cow and buffalo dung accounting for 344 and 315 Mt, respectively (Table 6). The corresponding dung produced from cow and buffalo for 2010 is estimated to be 368 and 362 Mt, respectively with a total production of 730 Mt. On average, 50% of the dung is used for making cakes to meet the fuel requirements for rural homes, and biogas compost and FYM are possible substitutes to use as livestock residues.

4. CROP RESIDUE MANAGEMENT PRACTICES

In India, residue management is crucial in the rice-wheat cropping system because large quantities of crop residues are left on the soil surface, especially where combines are used for crop harvest. This system churns out about 10.0 t/ha, pulling around 500 kg/ha of NPK and other nutrients from the soil, which poses a headache for farmers. Burning the leftovers after harvest is common, but it's not great – it can zap up to 80% of the soil's nitrogen and add to air pollution. While tilling residue into the soil is an option as in conventional tillage, it can hurt the yield of future crops by locking up nitrogen (N-Immobilization). Interestingly, keeping those residues on the soil surface instead of burning or tilling them actually boosts organic carbon and soil nutrients, cuts down on weed growth, and even reduces the need for herbicides. That's because it slows down the breakdown of residues, soil carbon loss, and erosion. Crop residues can be managed in the field in the following ways as mentioned in **Fig 2**.

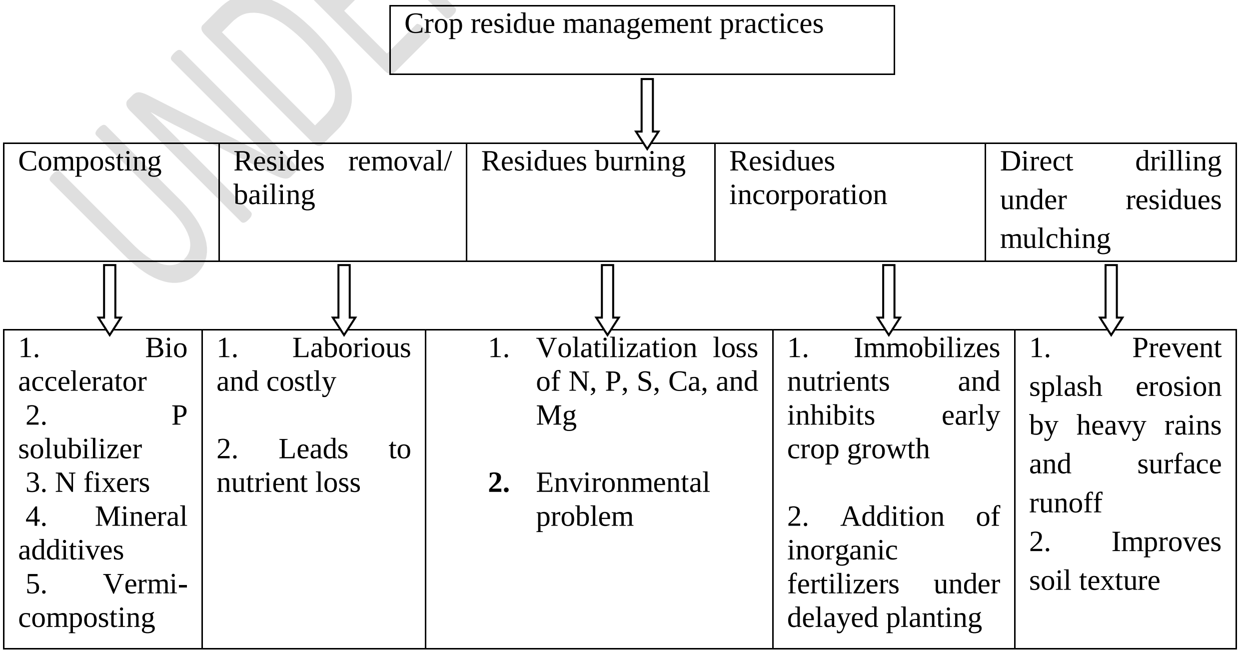


Figure 2. Crop residue management practices

Among the various crop management practices mulching helps to maintain the soil permeability, prevent erosion, reduce evaporation, and manage weeds as practiced in dry lands, ultimately boosting crop yields. It also affects soil temperature, potentially inhibiting pathogens by increasing saprophytic activity and reducing pathogenic fungi propagules. Therefore, mulching and conservation tillage can be considered as viable methods to retain soil moisture and nutrients because use of mulch as organic matter acts as a poor conductor of heat, effectively lowering soil temperature, maintaining moisture, and enhancing soil fertility for an extended period (Vaidya *et al*, 1995).

5. FACTORS AFFECTING RESIDUE DECOMPOSITION

The effect of residue incorporation on the succeeding crop depends on the amount of residues and time and method of incorporation. The flow diagram of factors affecting residues decomposition is given in Fig. 3.

Factors affecting crop residue decomposition

Crop residue quality factors	Edaphic factors	Management factors	Climatic factors
► Residue particle size ► Age of residues ► C/N ratio and N content ► Lignin	► Soil pH ► Soil temperature ► Soil moisture ► Soil aerobic anaerobic environment ► Soil available nutrients ► Soil salinity ► Soil texture, structure and clay content ► Indigenous micro/macro organisms	► Loading rate and quantity added ► Method, mode and accessibility ► Irrigation	► Temperature ► Moisture

Figure 3. Factors affecting crop residues decomposition

While we expect crop residue incorporation to pay off in the long run, its impact on short-term crop yields can be a bit of a surprise factor. Field experiments on different residue management methods often give us mixed signals, thanks to factors like the quality of the residue, soil conditions, and how healthy the previous crop was. Figuring out the agronomic effects of crop residues is like solving a puzzle, with their varying nutrient contents and other factors thrown into the mix. Sometimes, incorporating straw right away can actually backfire, causing a drop in yields because of nasty compounds released during decomposition or nitrogen getting tied up in the soil. The microbes in the soil break down residue and lock up nitrogen to keep it from washing away. This process depends on nitrogen quantity, temperature, and soil moisture. The microbes store the nitrogen for future use. Ideally, you want around 1.7-1.8% nitrogen in the residue for things to break down nicely. But in cereal straw, it remains 0.3-0.5% and in legumes from 1-1.5% and in green manure crops it is 2-2.5%, respectively. And hey, crop residues are good sources of K_2O, but not so hot for P_2O_5. So, there's no one-size-fits-all approach here; recycling cereal residue takes longer because it's got a higher C/N ratio.

6. BENEFIT S AND CONSTRAINTS OF RESIDUE MANAGEMENT IN AGRICULTURE

In general, crop residue recycling will have agronomic, environmental, and economic advantages, however, sometimes its mismanagements and other technical problems may result in its limited uses in the farmer's fields. In general, reducing fuel and labor costs required for intensive cultivation/ploughing, reducing sediment and fertilizer pollution of lakes and streams and. sustaining the soil fertility and productivity by the continuous mineralization processes are the major advantages of residue recycling with conservation tillage. The specific advantages and disadvantages are:

6.1. Advantages:

a. Agronomic benefits

i. Soil productivity improvement
ii. Increase in organic matter
iii. Soil water conservation
iv. Improvement in soil structure

b. Environmental benefits

i. Reduction in soil erosion
ii. Improvement of water quality
iii. Improvement of air quality
iv. Biodiversity increase
v. Carbon sequestration

6.2. Constraints of residue management and its adoption

i. Burning of crop residues
ii. Widespread use of crop residues for livestock feed and as fuel
iii. Transition from conventional farming to RR and no-till is difficult
iv. Marginal and semi-marginal farmers lack appropriate seeder/planters
v. Can slow germination and reduce yields
vi. Prevalence of weeds, disease and other pests may shift in an unexpected way
vii. May initially require more nitrogen fertilizer to increase mineralization
viii. Immobilization of nutrients (with high C: N ratio residues) and fear of attack of

several insect pests and diseases

ix. Prevalence of weeds, disease, and other pests may shift in unexpected way

x. Lack of knowledge about the potential of RR, and conservation agriculture to agricultural leaders, extension agents, and farmers

7. KEY MILESTONES IN RESIDUE MANAGEMENT IN INDIA AND ABROAD

Many short and long-term experiments in India and abroad showed the mixed response of crop residue incorporation across different types of land. A common consensus emerges: allowing a month for residue decomposition before planting the next crop tends to yield positive effects on subsequent crops. There's also growing interest in applying crop residues and other organic materials during fallow periods to potentially boost yields in the following crops. It's crucial for us to thoroughly weigh the pros and cons of different residue management options before recommending them to farmers. Over the past few decades, research, particularly in the rice-wheat cropping system of the Indo-Gangetic Plains (IGP), has greatly enhanced our understanding of how residue management impacts soil properties and fertilizer practices. Crop residues are now becoming increasingly prominent in modern scientific research, especially in the realm of site-specific nutrient management (SSNM), offering promising avenues for advancing agricultural practices.

7.1. Residue decomposition activities in India

- The brief history on crop residue management over the past showed that the latter 30-40 years are the key periods on its effective management, though the Indian history of it is about a century old (Table 7).
-

Table 7. Key milestones on residue management in India

Major practices followed	References
Use of green manuring and plant material as manure in the Mysore, Malabar and Chennai.	Francis Bacon (1801)
Long-term Manurial Experiment at Kanpur and Coimbatore.	Dr J W Leather (I IARI Chemist at Pusa Bihar, 1909)
Organic resides recycling with the use of straw was degraded by an aerobic cellulose decomposing organism, *Cytophaga hutchinsoni*	Hutcinson and Richards (1921)
Wad (1934) in Indore and Dr CN Acharya (1936) in Banglore had initiated Composting techniques in India	CJ Fowler (1922) and Sir Albert Howard
Research focus on organic residue recycling by perfecting the conditions for composting, identification of efficient microbial strains, use of additives, improvement in the quality of composts and their use in agriculture. IPNS.	IARI I Director- Rao Bahadur Vishwanath (1937)
Reaffirmation of 20th FAO meeting statement-"*What will happen to global agriculture in 2000 AD will largely depend on how we are able to spread scientific land and water use as well as organic residue recycling practices"*	GOI- PM Morarji Desai (1979)
Gobar gas plant initiation in rural homes, community and night soil biogas plants, utilization of sewage sludge, setting up of mechanical compost plants in cities with >300000 population. Green manuring and use of bio-fertilizers and other local practices.	Fifth 5 yrs plan (1975-1979)

Only with the ICAR initiated a national level project under All India Co-ordinated Agricultural Research Project (AICARP) in 1968 as 'microbiological decomposition and recycling of organic wastes' the residue recycling work took the fixed shape in Indian agriculture. AICARP launched programs at 11 stations country-wide .Some of the milestone works under this project are: Addition of rock phosphate 1 % (by w/w) supplemented with urea increase N and thereby the decomposition of rice straw by Cellulolytic fungi (*Aspergillus* spp.) - Guar *et al*. (1980).

- Importance of N_2 fixers *Azotobacter chrococcum* and Phosphate solubilizer (*Aspergilus awamori*) in the betterment of compost production - Guar *et al*. (1980).
- Compost quality improved by addition on low grade rock phosphate along with phosphorus solubilizing microorganisms - Tiwari *et al.(*1988).
- Use of Pyrites, RP and PSM has synergistic role in composting - Srinivas *et al*. (1992).
- Importance of vermin-composting and recycling of bio-degradable wastes into vermi-compost - Bhatanager and Paltha (1996).

7.2. **Residue management research findings at IARI, New Delhi**

Indian Agricultural Research Institute has made several academic and research contributions for the development of agriculture in India. The Agronomy Division, one amongst the prime divisions at IARI has already developed about 1000 dissertations with high-valued works towards the development of new agronomic techniques in field crops and cropping systems. About 107 theses works have been maintained on residue management either as integrated nutrient management (INM), or mulching, or green manuring (GM) in Agronomy from its inception up to 2010. Initially, they focused on wheat, maize, and rice, but later zeroed in on rice. About 50% of their research centered on rice and wheat, while the remaining 25% looked into maize and other rainfed crops and cropping systems. The nutrient substitution under lowland/irrigated ecosystems and the conserving moisture under rainfed and upland ecosystems are the major objective of residue management research in Agronomy at IARI**.**

7.2.1. Residue management and integrated nutrient management on growth and yield attributes of rice, grain yield and nutrient use efficiency of rice – wheat cropping system

The incorporation of wheat straw into the soil has pronounced but variable effects on the growth and yield of the subsequent crop of rice (Gangaiah, 1995, Tan, 1990**)**. Interestingly, green manuring in conjunction with wheat straw helped to mitigate the adverse effect of wheat straw on rice. Tan (1990) reported the significantly highest yield with green leaf manuring at 25 % and inorganic fertilizer at 75% concentration. Sharma and Mittra (1992) have also found that the incorporation of wheat straw in an acidic clay loam soil significantly increased the grain yield of rice and a residual effect was also observed on the succeeding wheat crop in West Bengal. Yadav *et al.* (2000) from seven locations in India, advocated that the rice grain yield in the treatment receiving 50% of the recommended N dose through wheat residues in general lower significantly by 4–18% than the yield obtained with the recommended fertilizer NPK dose. Also, the residual effect of wheat residues applied to rice was visible through the grain yield of subsequent wheat. Possibly, the wide C:N ratio and high lignin content of wheat residues impeded decomposition and immobilized native soil N and also only 50% of the N was applied and the rest was replaced by wheat residue-N, which may not be available. As a consequence, the productivity of rice that followed residue incorporation was adversely affected. In general, the incorporation of wheat straw in rice in heavier soils increased rice grain yields by 0.5–28% and also increased the yields of subsequent wheat by 10–25%. However, on lighter soils, rice yields declined because of the incorporation of wheat residues. Straw incorporation increased grain yield of rice by 5.2% (3.82 t/ha) over straw burning (3.63 t/ha) and 7.0% over straw removal (3.54 t/ha) (Table 8).

Table 8. Effect of wheat straw management practices on grain and straw yield (t/ha) of rice

Treatments	Grain yield (t/ha)			Straw yield (t/ha)		
	1992-93	1993-94	Pooled	1992-93	1993-94	Pooled
Straw removal	3.28	3.8	3.54	4.94	7.77	6.36
Straw burnt	3.34	3.92	3.63	5.03	8.49	6.76
Straw incorporation	3.65	4.0	3.82	5.63	8.38	7.00
SE m(±)	0.026	0.091	0.045	0.070	0.147	0.077
CD(5%)	0.102	NS	0.143	0.274	0.578	0.241

Source: Gangaiah (1995)

Applying nitrogen fertilizer at various stages of transplanted rice revealed that incorporating residues significantly outperforms removal and burning (Table 9).

Table 9. Total grain production (t/ha) of rice-wheat system as influenced by interaction effect of wheat straw management practices and N splits in rice

N splits	1994-95			1995-96			Pooled		
	Residue management practices			Residue management Practices			Residue management practices		
	Removal	Burnt	Incor.	Removal	Burnt	Incor.	Removal	Burnt	Incor.
½ at TP+ ½ at PI	8.24	8.37	8.29	10.13	10.18	9.98	9.19	9.27	9.13
1/3 at RI+ 1/3 at TP+1/3 at PI	8.59	8.66	9.01	10.48	10.41	10.80	9.53	9.54	9.90
SE m (±)		0.262			0.277			0.191	
LSD (P=0.05)		NS			0.792			0.537	

Source: Singh (1997)

The application of urea N at 3 splits recorded the highest yield of rice in both years of experimentations. Similarly, application of 25 kg/ha of Zn fertilizer in rice significantly increased the rice yield over the control and it was the highest in residue incorporation treatment (Table 10).

Table 10. Total grain production (t/ha) of rice-wheat system as influenced by interaction effect of wheat straw management practices and zinc application in rice

Zinc sulphate (kg/ha)	1994-95			1995-96			Pooled		
	Residue management practices			Residue management practices			Residue management Practices		
	Removal	Burnt	Incorp.	Removal	Burnt	Incor.	Removal	Burnt	Incor.
0	8.81	8.78	9.74	10.53	10.55	11.37	9.67	9.66	10.55
25	9.03	9.07	10.57	10.44	11.05	12.08	9.74	10.06	11.32
SE m (±)		0.453			0.480			0.330	
LSD (P=0.05)		**1.295**			**1.371**			**0.930**	

Source: Singh (1997)

7.2.2. Residue management and integrated nutrient management on weed management

The major monocot weeds present in the field wheat weeds were *Cynodon dactylon*, *Phalaris minor*, and *Avena sterilis*. Conventional tillage reduced the growth of total weeds by 30 % and reduced the weed that of monocots by 50% as compared to no-tillage practice. The incorporation of rice straw reduced the population by 14%, 39 %, and 28% of monocots, dicots, and total weeds, respectively over the straw removal.

Table 11. Population of monocot weeds (Nos./ 0.25 m^2) in wheat crop as affected by tillage with different residue management practices at 40 DAS (1993-94) $(x+0.5)^{1/2}$transformed

Residue management practices	No tillage	Conventional tillage
Straw incorporation	2.38(5.33)	2.11(4.00)
Straw burning	3.14(9.67)	1.56(2.0)
Straw removal	4.12(17.33)	1.10(1.00)
SEm (±)	0.401	
CD (5%)	1.262	

Note: Values in parenthesis indicate original values. *Source: Aipe (1995)*

The result as cited in Table 11 indicated that the interaction effect of tillage and residue management was significant with respect to number monocot weeds. When straw was either burnt or removed the monocot weed population was significantly higher under no-tillage as compared to conventional tillage. When straw was incorporated, the monocot weed population was similar under no-tillage and conventional tillage which shows that the under no-tillage practice straw acts as mulch to smother the weed growth whereas under conventional tillage repeated the cultivation to incorporate straw reduced weed population.

7.2.3. Residue management and integrated nutrient management on moisture conservation

The maximum consumptive use of water (426.9 and 302.4 mm) was recorded with FYM @5 t/ha + dust mulch+ straw mulch closely followed by Kaolin+ straw mulch (415.9 and 296.9 mm) and dust mulch +straw mulch (404.8 and 285.6 mm) and minimum with no mulch (382.3 and 256.6 mm) in the year 2003 and 2004, respectively (Table 12). Similarly, the moisture conservation practices showed improvement in water use efficiency of pearl millet in terms of grain equivalent yield. The moisture conservation practices also altered the soil moisture extraction pattern in all the three layers viz. 0-30, 30-60 and 60-90 cm.

Table 12. Effect of residues and moisture conservation practices on consumptive use, water use efficiency and rate of moisture use in pearl millet field

Treatments	Consumptive use (mm)		WUE (kg/ha)		Rate of moisture use (mm/day)	
	2003	2004	2003	2004	2003	2004
No mulch	328.29	265.62	6.26	7.64	4.44	3.69

Dust + Straw mulch	404.77	285.16	7.53	9.05	4.70	3.96
Kaolin+ Straw mulch	415.97	296.86	7.57	9.20	4.83	4.12
FYM@5t/ha + Dust mulch + Straw mulch	426.97	302.36	8.24	10.16	4.96	4.19

Source: Tetarwal (2006)

7.2.4 Residue management and integrated nutrient management on economics and systems productivity

The general economics of different cropping systems have been shown in Table 13 and 14 and Fig 4 and results revealed that intercropping or sequential cropping is better in gaining high return per rupee invested. The practice of maize-mung system is 28% higher in net return per Re invested under no stover treatment while it is 38% higher with stover management treatments over the sole maize planting (Table 13).

The integrated use of organic and inorganic nutrients is of vital importance to maintain the long-term soil fertility and crop productivity. The conjunctive use of either sunhemp, or subabul green leaf manure or dhaincha + wheat straw + N 40 kg/ha, recorded almost the highest total profit (10497,10332, and 10164/ha, respectively) in rice-mustard cropping system over their sole application and control **(**Vidhya Sagar, 1997)**.** Residue recycling hence seem profitable and suggested to use both in irrigated and rainfed ecosystems.

Table 13. Economics of maize and maize–mungbean cropping system as affected by their stover management

Treatments	Cropping system	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	Return per rupee invested (Rs)
No stover	Maize crop	2016	3672	1656	0.82
	Maize-mung	3862	7948	4086	1.05
	% more than maize crop	91.57	116.44	146.74	28.05
Stover	Maize crop	2350	4030	1680	0.71
	Maize-mung	4196	8306	4110	0.98
	% more than maize crop	78.55	106.10	144.64	38.02

Source: Singh (1990)

The yields of greengram, mustard and cowpea were significantly influenced due to different tillage, residue management and crop establishment practices (**Table 14**).

Table 14. System productivity (t/ha) due to residue management effects in greengram – mustard – cowpea cropping system (pooled mean of 3 years)

Treatments	Green gram	Mustard	Cowpea*	MEY	Net Return** (Rs/ha)
No fertilizer + No Residue	0.659	1.050	2.548	3.562	32,661
No fertilizer + Residue	0.707	1.170	2.749	3.875	38,449
Fertilizer + No Residue	0.762	1.452	2.866	4.318	40,028
Fertilizer + Residue	0.840	1.620	3.132	4.761	53,851
CD (P<0.05)	0.038	0.065	0.184		

* Green pod yield; MEY, Mustard equivalent yield; WEY, wheat equivalent yield; ** For the 3rd cropping cycle
Source: Behera and Sharma (2009)

Fertilizer application supplemented with residues significantly increased yield for all three crops, showing positive responses with varying levels of improvement. The treatment receiving fertilizer supplemented with crop residues recorded the highest system productivity at 4.76 t/ha. Additionally, the interaction effect of tillage and crop establishment practices with fertilizer and residues for mustard crop was significant, with conservation tillage (zero-tillage followed by fertilizer and residue application) producing the highest mustard yield at 1.71 t/ha. This system also resulted in the highest net return (Rs. 53851). The response of wheat to nitrogen was quadratic under straw incorporation (SI) and straw removal (SR) practices, whereas it was linear under straw burning practices. The economic optimum dose of N was 134 kg N/ha with SI and 189 kg N/ha with SR practices. The grain yield with SI at the economic optimum dose was 45% higher than that obtained with SR. Additionally, when residue was removed, the wheat crop required 35.1 to 44.3 kg/ha more N compared to SI practice for targeted yields of 3.5 and 4.0 t/ha, respectively.

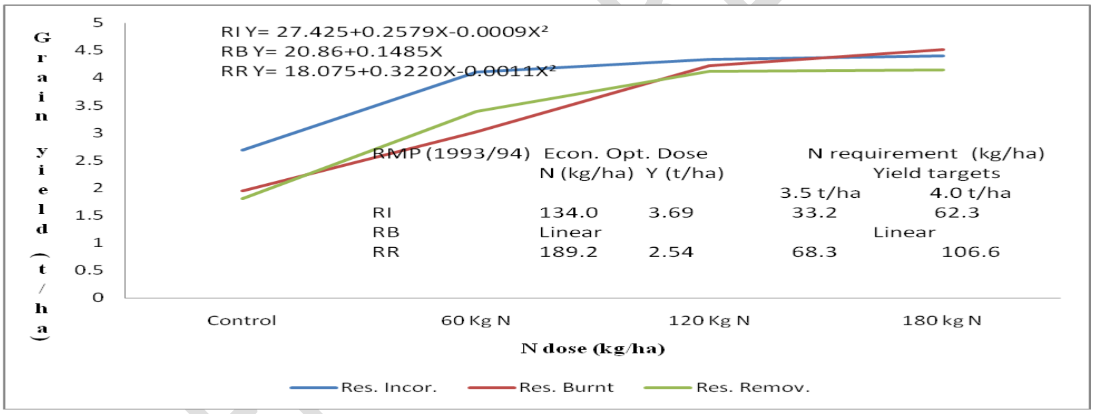


Fig. 4. Optimum economic dose of N, optimum economic yield and N requirement for yield targets for wheat of 3.5 and 4.0 t/ha for various residue management practices
(Source: Apie K C, 1995)

7.2.5. Residue management and integrated nutrient management on physico-chemical properties of soil and nutrient balance

Field saturated hydraulic conductivity (Kfs) measured at 15 cm by Guleph Permeameter were in the order of CT+WS> CT> ZT+WS>ZT, whereas order was reversed for bulk density (BD). The above trend confirmed the earlier findings that soil compaction were maximum under zero tillage without residue, whereas wheat straw incorporation through conventional tilling keeps the soil bulk density within optimum range. Least Limiting Water Range (LLWR) value of which if more than 10% is an indicator of good soil structural condition remained widest in CT+ WS (14.2% and lowest in ZT 95.2% (Table 15). Results thus indicated that soil structural condition of all treatments except CT+WS became poor at harvest. Gangwar *et al*. (2009) also conducted a field study during 2003-07 at

Modhipuram to assess the effect of rice crop establishment methods on hybrid rice and their carryover effect on wheat, Indian mustard and chickpea yield, energy use and soil properties. Significantly higher infiltration rate (1.32 cm/hr) and lowest bulk density (1.46 Mg/m^3) was recorded under direct seeding dry bed while organic C, total N, available P and K were increased by 4.08, 31.82, 7.59 and 30.5% over their initial content under mechanical transplanting /puddled. The higher organic C in mechanical transplanting puddled was because of flooding and puddling which caused major chemical changes in soil, that also affect transformation, availability of nutrients and organic C dynamics. Similarly, Vanilla and Datta (2008) investigated the impact of tillage on the stability and physico-chemical properties of clay-humus complex in rice-wheat cropping reported that significantly higher CEC was observed in no-tillage treatment compared to conventional tillage treatment.

Table 15. Soil physical properties at harvest (0-15cm) under different tillage and crop residue management systems

Treatment	Saturated Hydraulic conductivity (cm/hr)	BD (Mg/m^3)	LLWR (%)
Conventional tillage	38.9	1.62	9.3
Conventional + Wheat straw	76.4	1.54	14.2
Zero tillage	22.4	1.68	8.5
Zero tillage+ wheat straw	4.76	1.78	5.2

Source: Aggrawal *et al*. (2009)

Organic carbon (%) content in soil after each crop harvest increased due to straw incorporation over its initial content (0.55%) and after 2 years of rice and wheat the organic carbon content was 0.61%. Straw burning and removal resulted in slight decrease in organic carbon in the soil from initial content. The decline in available P was more due to straw burning, while available K decline was more due to removal of the straw management practices. Straw management resulted in lowest soil pH values after 2 yrs of rice-wheat system (Table-16).

Table 16. Changes in soil fertility as affected by straw management practices after 2 years of rice-wheat system

Soil parameters	Treatments		
	Straw removal	Straw burning	Straw incorporation
Organic C (%)			
Final	0.53	0.54	0.61
Balance (±)	-0.02	-0.01	+0.06
Available P (kg/ha)			
Final	17.01	16.58	17.46
Balance (±)	-4.59	-5.02	-4.14
Available K (kg/ha)			
Final	253.0	265.55	267.22
Balance (±)	-64.0	-52.53	-50.22
Soil pH			
Final	8.27	8.28	8.20

Balance (±)	-0.23	-0.22	-0.30

Initial values: OC (0.55%); Avail P (21.60 kg/ha); Avail. K (318.08 kg/ha); Soil pH (8.5) Source: Gangaiah (1995)

OC decreased with straw removal and burning but increased with incorporation (0.06%). The lowest declines in available P and K were in SI plots, while soil pH declined the most when straw was incorporated. Straw burning led to the highest decline in available P, and straw removal resulted in the highest decline in available K. Rice and wheat residues can be safely incorporated without harming subsequent crops (Sharma and Behera, 2009; Behera and Sharma, 2010). Incorporating residues into the soil is a safe and eco-friendly practice that doesn't harm crops, especially in warmer regions with slowly boosts soil fertility over time.

Dual-purpose legumes and Leucaena leaf mulching enhance long-term productivity and soil fertility in various cropping systems (Sharma and Behera, 2009; Behera and Sharma, 2010). Incorporation of wheat crop residues in combine harvested areas six weeks before rice transplanting has been found beneficial for rice crops. The green manuring with *Sesbania* can provide 30-40 kg N/ha and increased fertilizer use efficiency. The addition of N through legume residues varied from 11.5 to 38.5 kg/ha in intercropped systems and 17.5 to 83.5 kg/ha in sole cropping which improved the productivity of following wheat to a variable extent. N economy in wheat was 21 kg/ha due to residue incorporation of intercropped green gram, cowpea, and groundnut and 49-56 kg N/ha of sole green gram, cowpea, and groundnut. Maize-based cropping systems exhibit higher OC and KMnO4 N levels in sole legume plots compared to wheat-based systems. (Table 17; Sharma and Behera, 2009; Behera and Sharma, 2010).

Table 17. N balance under different cropping systems as affected by residues application

Cropping system	Total N inputs (kg/ha)	Total N outputs (kg/ha)	Apparent N balance (kg/ha)	Actual change over initial N (kg/ha)
Intercropping systems (2002-03 and 2003-04 mean)				
Sole maize- wheat	360.0	366.1	-6.1	5.0
Maize+ Blackgram-wheat	409.9	371.3	38.6	9.7
Maize+ greengram-wheat	411.9	387.6	42.3	25.8
Maize +cowpea-wheat	417.2	382.1	35.1	16.2
Maize +Groundnut-wheat	492.8	371.2	121.6	16.6
Maize +soybean-wheat	455.8	396.4	59.4	21.5
Sole cropping systems (2003-04)				
Blackgram- wheat	147.5	118.4	29.1	-8.2
Green gram-wheat	164.1	154.3	9.8	18.3
Cowpea-wheat	176.3	145.3	31.0	23.5
Groundnut-wheat	295.8	174.3	121.5	38.6
Soybean-wheat	229.5	211.1	18.4	32.1

Source: Sharma and Behera (2009)

7.3. Conservation agriculture and residue management studies in abroad

To compare the effects of no-tillage (NT) with continuous apple orchard with those of conventional tillage (CT) in a 41 years of wheat-soybean rotation (Rahman *et al*., 2008) and another of puddling (PD) with continuous rice on the characteristics of a pumice Andisol in a temperate region of North Japan (Glab and Kulig, 2008) the highest values of bulk density, penetration resistance, pH, C/N ratio, exchangeable Na, Fe and Mn were observed for puddling than NT and CT . On the other hand, organic matter, EC, N, exchangeable K, Ca and Cu were significantly higher for NT than CT and puddling. In contrary, a field experiment to quantify the effect of fodder radish mulching and different tillage systems in wheat production at Pursy, Poland, reduced tillage without mulch or mould board plough increase the soil density. This relation was confirmed in the 10-20 cm soil layer. However, in the upper, 0-10 cm soil layer with residue mulch the bulk density decreased and reached the similar value as those obtained at conventional tillage (CZ and CM). The inverse effect was recorded in total porosity; mulch addition increased the total porosity in more compacted soil under reduced tillage (RT). Residue mulch decreased bulk density in compacted soils particularly in no-tillage system and this can be ascribed to higher soil carbon content and biotic activity. Similarly, Gill *et al*. (2009) conducted field research in the semi-arid Pampa of Argentina, and observed some of the soil chemical properties as affected by tillage system and crop sequence. Soil pH tended to be acidic under crop rotation compared with continuous soybean, but was not affected by the tillage system. Soil organic matter content was 18% higher when soybean was under zero-tillage, compared with reduced tillage. Organic matter was greater in soybean with maize as previous crop, compared with continuous soybean or soybean as preceding crop. Same tendency was observed with total N, with soybean under zero-tillage. Total N was 13% higher than under reduced tillage. Total N was the highest in soybean with maize as preceding crop. Under zero-tillage and in the maize/soybean rotation scheme, soybean yield was 5% higher than under reduced tillage. In continuous soybean, yield was 7% higher under zero-tillage than under reduced tillage.

Limousin and Tessier (2007) observed in their study in Essone, France that no-tilled soil, compared to tilled soil, exhibited a distinct vertical gradient and notably higher organic carbon content. This was attributed to the practice of conventional tillage, which uniformly mixed organic matter and accelerated its mineralization rate. The bulk density analysis revealed an enrichment of 11.4% for maize inter-rows in no-tilled soil compared to tilled soil. . The maize inter-row was significantly more acidic (5.58) than the row (5.95). It was due to the alkalinity of organic matter accumulated preferentially under the row, which could have counterbalanced the acidification. Despite a marginal decrease of one unit in pH, the cation exchange capacity (CEC) of no-tilled soil was 25% lower than tilled soil, possibly due to due to the high density of pH dependent charges of organic matter.

Roldan et al. (2003) reported that, total organic N (TON) was greater with residue additions of ≥ 66% than without residue or conventional tillage. In contrast to TON, total organic carbon (TOC) increased with all residue additions relative to conventional tillage (CT). Interestingly, the introduction of legumes did not significantly influence TON or TOC. Available soil P was significantly increased by the adoption of no-tillage concerning conventional tillage. However, the planting of leguminous crops resulted in available P values similar to conventional tillage. Neither the addition of crop residue nor the presence of legumes had a notable impact on soil extractable potassium.

Further research by Roldan et al. (2007) in Rio Brao, Mexico from 2000 to 2004 underscored the significant influence of tillage practices on the electrical conductivity (EC) and pH of soils cultivated with maize and beans. While soil pH was higher under mould board ploughing (MP) compared to no-tillage (NT), soil EC was lower under MP. Nitrate levels were observed to be higher under NT. Available phosphorus and extractable potassium remained unaffected by the tillage system or soil depth. Crop type, tillage system and soil depth had significant effects on soil organic carbon. In the 0-5 cm layer, organic carbon was greater under NT than under MP, particularly soil cultivated with bean. Below the 0-5 cm layer, organic C was lower under both tillage system but smaller values were with bean. Mould board ploughing resulted in the lowest OC content throughout the 0-15 cm soil layer.

Zero-tillage maize increases net returns, water use efficiency, and it is innovative, simple and resource conservative technology (Reddy and Veeranna, 2008). Kushwaha and Singh (2005) reported the minimum yield of rice and barley in zero-tillage without residue (ZT-R), and maximum in minimum tillage with residue (MT+R) in a tropical dry land agro-ecosystem. Residue retention alone (CT+R) increased the available N in soil in both barley and rice over control.

SUMMARY, CONCLUSIONS AND FUTURE RESEARCH THRUST

Crop residues are important not only for nutrient supply but also vital for maintaining better soil physical, chemical and biological properties. Crop residue recycling was found valuable to increase the systems productivity and soil health by their nutrient substitution, water economization and easy access in the farm periphery. Residue decomposition is mainly governed by the amount and quality of crop residues added and their management, climate and edaphic factors. In India, the major focuses of residue recycling studies are only on irrigated and intensive tillage systems, neglecting the rainfed and conservation tillage practices. Hence, need for standardizing the methods for determining residue characteristics (lignin, polyphenol) and decomposition rates before rating the nutrient quality index is of vital importance. Development of better technology for *in-situ* incorporation and rapid decomposition of crop residues by appropriate agronomic management is the real need of the days. Efficient composting techniques for crop residues using suitable microbes, chemical fertilizers and management practices are suggested for its efficient utilization. Hence, studies on residue management in combination with tillage, nutrient, water and weed management in diversified cropping systems should be initiated soon. Multi-disciplinary team work is the utmost need for its effective residue recycling.

REFERENCES

Aggarwal, P., Sharma, A. R, and Mittal, R. B. 2009. Soil physical properties at harvest (0-15 cm) under different tillage and crop residue management systems. *Annual Report*, Division of Agricultural Physics (2009/010), IARI, Pusa, New Delhi, India.

Agricultural Statistics at a Glance 2001. Directorate of Economics and Statistics, Ministry of Agriculture, Government of India.

Aipe, K. C. 1995. Effect of tillage, rice residue management and fertilizer use on productivity and nutrient uptake in rice-what cropping system. Ph. D Thesis, Division of Agronomy, IARI, New Delhi.

Anonymous 1997. Basic Animal Husbandry Statistics. Government of India.

Behera, U. K and Sharma, A.R. 2010. Conservation agriculture for enhancing resource use efficiency, carbon sequestration, soil and crop productivity. In: *Proceeding of 19th World Congress of Soil Science*, Brisbane, Australia, 1-6 August, 2010.

Bhardwaj, K. K. R. 1995. Recycling of crop residues, oil cakes and other plant production in agriculture. In*: Recycling of crop, animal, human and industrial wastes in agriculture*. (H.L.S. Tandon Ed.), Fertilizer Development and Consultation Organization, New Delhi, India. pp. 9–30.

Bhatnagar, R. K. and Palta, R. K. 1996. Earthworm vermiculture and vermicomposting. Kalyani Publishers, New Delhi, pp. 47-48.

Directory of Indian Agriculture 1997. *Directory of Indian Agriculture*. Centre for Monitoring Indian Economy Pvt Ltd., Mumbai, India.

FAI. 2009. Fertilizer Statistics: 2008-09, 54th Edition. The Fertilizer Association of India, New Delhi.

FAO. 2006. Food and Agriculture Organization of the United Nations, conservation agriculture website. http://www.fao.org/ag/ca/

Gangaiah, B. 1995. Residue and fertilizer management in rice-wheat system. Ph. D. Thesis, Division of Agronomy, IARI, New Delhi.

Gangwar, K.S., Chaudhary, V.P., Gangwar, B. and Pandey, D.K. 2009. Effect of crop establishment and tillage practices in rice based cropping system. *Indian Journal of Agricultural Sciences* **79**(5): 334-339.

Gaur, A. C., Sadashivam, K. V., Magu, S.P. and Mathur, R. S. 1980. Microbiological decomposition and recycling of farm and city wastes. *Progress Report*. IARI, All India Co-ordinated Research Project, IARI, New Delhi.

Gill, S.V., Meriles, J., Conforto, C., Figoni, G., Basanta, M., Lovera, E. and March, G.J. 2009. Field assessment of soil biological and chemical quality in response to crop management practices. *World Journal of Microbiology and Biotechnology* **25**: 439-448.

Glab, T. and Kulig, B. 2008. Effect of mulch and tillage system on soil porosity under wheat (*Triticum aestivum*). *Soil and Tillage Research* **99**: 169-178.

Hobbs, P.R., Sayre, K. and Gupta, R. 2008. The role of conservation agriculture in sustainable agriculture. *Philosophical transactions of the royal society B* **363**: 543-545.

Huggins, D.R. and Reganold, J.P. 2008. No-till: the quiet revolution. Scientific American, July issue; pp. 75-77.

Kimsella, J. 1995. The effect of various tillage systems in soil compaction. p. 15-17. In: *Farming for a better environment*, a white paper, soil and water conservation society, Ankeny, Iowa, USA, pp.67.

Kumar, K., and Goh, K.M. 2000. Crop residue management: effects on soil quality, soil nitrogen dynamics, crop yield, and nitrogen recovery. *Adv. Agron*. **68**: 197–319

Kushwaha, C.P. and Singh, K.P. 2005. Crop productivity and soil fertility in a tropical dry land agro-ecosystem: impact of residue and tillage management. *Experimental Agriculture* **41**: 39-50.

Limousin, G. and Tessier, D. 2007. Effect of no-tillage on chemical gradients and top soil acidification. *Soil and Tillage Research* **92**: 167-174.

Pingali, M., Vignozzi, N. and Pellegrini, S. 2004. Soil structure and the effect of management practices. *Soil and Tillage Research* **79**: 131-143

Rahman, M.H., Okubo, A., Sugiyama, S. and Mayland, H.F. 2008. Physical, chemical and microbiological properties of Andisol as related to land use and tillage practice. *Soil and Tillage Research* **101:** 10-19

Ramakrishna Parama, V. R. and Biswas, D. R. 2009. Assessment, safer disposal and utilization of agricultural and industrial wastes. *J Indian Society of Soil Science* **57**(4): 502-512.

Rattan, R. K., Singh, M.P., Singh, R.O. and Singh, U.S.P. 1996. Long-term effect of inorganic and organic-inorganic nutrient supply system on yield trends in rice-wheat cropping system. *J. Appl. Biol.* **6**:56–58

Reddy, P.R.M. and Veeranna, G. 2008. Rice-zero tillage maize proved economical in Andhra Pradesh. *Indian Farming* **58** (5); 8-9.

Roldan, A., Caravaca.F., Hernandez, M.T., Garcia, C., Sanchez-brito, C., Valasquez, M. and Tiscareno, M. 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). *Soil and Tillage Research* **72:** 65-73.

Roldan, A, Garcica, J.R.S., Algaucil, M.M. and Caravaca, F. 2007. Soil sustainability indicators following conservation tillage practices under sub tropical maize and bean crops. *Soil and Tillage Research*, **93:** 273-282.

Sarkar, A., Yadav, R.L., Gangwar, B. and Bhatia, P.C. 1999. Crop residues in India. *Tech. Bull***.**, Project Directorate for Cropping System Research, Modipuram, India.

Sen, H. S. 2009. Soil and water management research: A review *vis a vis* ecology and climate change. *Journal of Indian Society of Soil Science* **57** (4): 398-411.

Sharma A. R and. Behera, U. K. 2009. Recycling of legume residues for nitrogen economy and higher productivity in maize (*Zea mays*)-wheat (*Trtiticum aestivum*) cropping system. *Nutr Cycl Agroecosyst* **83**:197-210.

Sharma, A. R. 2007. Agronomy in the Service of Nation: Six Decades of Research and Education at IARI (1947-2006). Division of Agronomy, IARI, Pusa, New Delhi.

Sharma, A.R. and Mittra, B.N. 1992. Integrated nitrogen management in rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system*. Indian J. Agric. Sci.* **62**:70–72

Sharon, J. 2005. Report of the National Coordinator, 2004-RWC-IGP, India. In: presented at 13th regional technical coordination meeting of the RWC, February 6-8, 2005, Dhaka, Bangladesh. RWC, New Delhi, India.

Singh, A. V. 1990. Studies on N economy in kharif maize as affected by P- fertilizer and stover management in preceding greengaram. Ph. D Thesis, Division of Agronomy, IARI, New Delhi.

Singh, M. 1997. Studies on wheat residues and fertilizer management in basmati rice-wheat cropping system. Ph. D Thesis, Division of Agronomy, IARI, New Delhi.

Srinivas, K.N., Balakrishan, A.N. and Radhakrrishna, D. 1992. Role of pyrite and phosphorus source in the enrichment of coconut coir pith compost with phosphate solubilizing fungi. *Current research* **21**: 65-66.

Tan, P. S. 1990. Studies on the optimizing nitrogen supply system through usage of organic and inorganic sources in rice-mustard cropping sequence**.** Ph. D Thesis, Division of Agronomy, IARI, New Delhi.

Tandon, H.L. S. 1997. Potential of organic resources as plant nutrients in India. In: *Integrated nutrient management (INM) in a sustainable Rice- Wheat Cropping system* (A. Mahajan and R. D. Gupta Eds). pp.101-107

Tetarwal, J. P. 2006. Moisture conservation and nutrient management studies in sole and intercropped pearlmillet under rainfed conditions. Ph. D Thesis, Division of Agronomy, IARI, New Delhi.

Tiwari, V. N., Pathak, A.N. and Lehri, L. K. 1988. Manurial value of compost enriched with rock phosphate and microbial inoculants to greengram. *Journal of the Indian Society of Soil Science* **36** : 280-283.

Vaidya, V.B., Varshneya, M. C., Bote, N. L. and Naidu, J.R. V. 1995. Estimation of thermal efficiency and apparent reflectivity of mulches using soil temperature. *J. Mahrashta Agril. Universities* **20** (3): 341-344.

Vennila, A. and Datta, S.C. 2008. Stability and physico-chemical properties of clay-humus complexes – influence of tillage and puddling. *Clay Research* **27 (**1&2): 35-50.

Vidya Sagar, G. E. Ch. 1997. Studies on direct and residual effects of green manures in combination with wheat straw and fertilizer N on rice-mustard cropping system under upland conditions. Ph.D Thesis, Division of Agronomy, IARI, New Delhi.

Yadav, R.L., Dwivedi, B.S., Kamta Prasad, Tomar, O.K., Shurpali, N.J. and Pandey, P.S. 2000. Yield trends and changes in soil organic-C and available NPK in a long-term rice-wheat system under integrated use of manures and fertilizers. *Field Crops Res*. **68:** 219–246.