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Consequence of divergent crop residue and green manuring practices on soil nutrient balance: A review

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Abstract
Immensely and unremitting rise in cost of fertilizers bound us to review the different management practices including utilizing crop residues and green manuring with some new findings, which can enhance soil fertility and lower the burden of high cost of cultivation. Approximately 500–550 million tonnes (Mt) crop residues are generated through different crops every year in the country. Traditionally crop residues have various uses such as animal feed, fodder, fuel, roof thatching, packaging and composting. It is estimated that one tone rice residues contains 6.1 kg nitrogen (N), 0.8 kg phosphorus (P), and 11.4 kg potassium (K). Nevertheless, a large part of the residual harvest being handle inappropriately, which fragile the world's food–production and contribute to undesirable bio–spheric changes. Such malpractices are common in developing countries, where only a small amount of residue are being recycled, while unacceptably large amounts are burned. Green manure crops are another important source for recycling of plant nutrients. Incorporation of one tonne *Sesbania aculeata* green matter approximately accumulated 30.3 kg N, 7.0 kg P and 13.0 kg K ha^{-1}. Generally farmers are unaware about systematic utilization of crop residues and green manure crops and their usefulness in maintaining soil nutrient balance and overall health, because of which either they keep out themselves from these practices or unable to perform appositely. In this article, efforts were made to quantify residue production by different crops as well as green manure crops, their nutrient compositions, decomposition mechanism of residues in soil and finally we explained the ways and means for crop residue management and green manuring practices for efficient nutrient recycling, supported with findings from our research.

Keywords: Crop residue, Decomposition mechanism, Green manuring, Nutrient recycling, Soil fertility

Introduction

Crop residue

Crop residue referred to any plant material remaining after removal of economical part of the crop which includes leaves, stalk, roots etc. Crop residues retain considerable quantity of plant nutrients and can be utilized as good source of plant nutrients, primary source of organic matter and important components for the stability of agricultural ecosystems (Kabirinejad *et al*. 2014) [7]. Recycling of crop residues is one of the ways of improving soil nutrient content and maintaining soil productivity (Beres and Kazinczi 2000) [3].

Quantification of crop residue

Globally, the total crop residue production is estimated as 3.8 billion tonnes per year (Lal 2005) [11] which includes 74% from cereals, 8% from legumes, 3% from oil crops, 10% from sugar crops and 5% from tubers. It is estimated that approximately 500–550 Mt crop residues are generated through different crops, every year in the country (Table 1).
Among different crops, cereals generate maximum residues (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt) and sugarcane (12 Mt) (MNRE 2009).

Residues as resources

Crop residues are vital natural resource for conserving and sustaining soil productivity, upon mineralization; crop residue supplies essential plant nutrients (Walters *et al*. 1992) [24]. About 25% N and P, 50% sulphur (S) and 75% K uptake by cereal crops are retained in crop residues, making them valuable nutrient sources (Kumar *et al*. 2015) [10]. The world's crop residues contain an equivalent of approximately 1.3 Giga tonnes (Gt) of cellulosic fibres and 18 mega joule (MJ) energy kg^{-1} dry residues (Smil 1999) [22]. The nutrient composition of various crop residues is given in Table 2.

Table 1: State wise generation and remaining surplus of crop residues in India (Mt/yr)

State	Crop residues generation (MNRE 2009) [15]	Crop residues surplus (MNRE 2009) [15]	Crop residues burnt (Pathak *et al.* 2010) [16]
Andhra Pradesh	43.89	6.96	2.73
Arunachal Pradesh	0.40	0.07	0.04
Assam	11.43	2.34	0.73
Bihar	25.29	5.08	3.19
Chhattisgarh	11.25	2.12	0.83
Goa	0.57	0.14	0.04
Gujarat	28.73	8.9	3.81
Haryana	27.83	11.22	9.06
Himachal Pradesh	2.85	1.03	0.41
Jammu & Kashmir	1.59	0.28	0.89
Jharkhand	3.61	0.89	1.10
Karnataka	33.94	8.98	5.66
Kerala	9.74	5.07	0.22
Madhya Pradesh	33.18	10.22	1.91
Maharashtra	46.45	14.67	7.41
Manipur	0.90	0.11	0.07
Meghalaya	0.51	0.09	0.05
Mizoram	0.06	0.01	0.01
Nagaland	0.49	0.09	0.08
Odisha	20.07	3.68	1.34
Punjab	50.75	24.83	19.62
Rajasthan	29.32	8.52	1.78
Sikkim	0.15	0.02	0.01
Tamil Nadu	19.93	7.05	4.08
Tripura	0.04	0.02	0.11
Uttarakhand	2.86	0.63	0.78
Uttar Pradesh	59.97	13.53	21.92
West Bengal	35.93	4.29	4.96
India	501.76	140.84	92.81

Table 2: Nutrient composition in residues of important crops

Crop residues	N (%)	P (%)	K (%)	References
Rice	0.5–0.8	0.16–0.27	1.4–2.0	(Dobermann and Fairhurst 2002) [4]
Wheat	0.61–0.65	0.085–0.09	1.67–1.69	(Yadav *et al.* 2017) [25]
Maize	0.84–0.90	0.10–0.14	1.09–1.19	(Logah 2011) [12]
Soybean	2.83–3.07	0.62–0.64	1.0–1.23	(Almaz *et al.* 2017) [1]
Mung bean	1.32	0.33	1.78	(Singh *et al.* 2008) [21]
Peanut	1.07	0.47	3.42	(Kaewpradit *et al.* 2009) [8]

Chemistry of crop residues decomposition

Crop residue is composed of lignin, cellulose, hemicellulose, and nutrients. Micro–organisms breakdown these compounds, and the decomposition rate is largely affected by types of crop residue, moisture and temperature. Some of the conditions that favour decomposition of residue include warm, moist weather, size of residue, and contact between residue and soil.

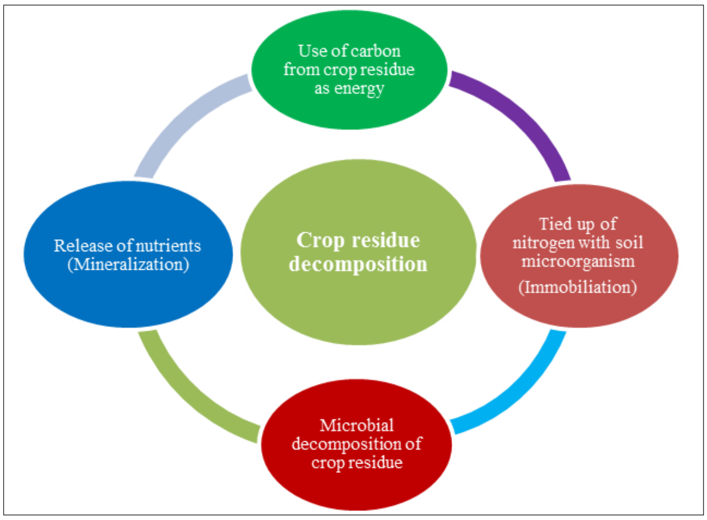


Fig 1: Crop residue decomposition mechanism through soil micro organisms

Decomposition process relies on immobilization and mineralization, which both involve soil microbes. Soil microbes feed on the carbon in crop residues and require N as energy source. The process of immobilization occurs when N is consumed by soil microbes. Nitrogen within the residue remains tied up or immobilized until decomposition is complete and is released by soil microbes through mineralization (Fig. 1).

Residue application practices

Crop residue can be applied in sundry ways to supply plant nutrients to soil. These include incorporation into soil, retention on soil surface, application as mulch and use as compost materials.

1. Residue incorporation

Incorporation of crop residues into the soil and allowing them to decompose not only improves the physical, chemical and biological properties but also returns almost all the nutrients retained in the residue to the soil and improves soil nutrient levels. Thorat *et al*. (2015) [23] reported that available soil nutrients *viz.* N, P and K was improved through wheat residue incorporation as compare to no residue under rice–wheat cropping system (Table 3).

2. Residue retention

Retention of crop residues on soil surface after harvesting is considered to be an effective measure for soil fertility enhancement. Retaining the straw and chaff on the surface of a field offers many benefits like increase in water infiltration, reduced evaporation, increased soil organic matter, improved soil structure and plant nutrient recycling, weed suppression and erosion control.

Table 3: Effect of crop residues management on chemical properties of soil under rice–wheat rotation

Parameter	Initial status (Depth 10–20 cm)	Retained	Incorporation	Removed	Burnt
Organic carbon (%)	0.46	0.53	0.58	0.43	0.47
Available N (Kg ha^{-1})	64.6	89.0	83.0	32.0	21.0
Available P (Kg ha^{-1})	25.8	39.0	42.0	21.0	29.0
Available K (Kg ha^{-1})	52.1	67.0	69.0	48.0	55.0

Source: (Thorat *et al*. 2015) [23]

3. Crop residue as mulch

Crop residues contain substantial quantities of plant nutrients. Crop residues when used as mulch, can improve soil fertility by recycling of plant nutrients, conserve soil moisture and helps in building of soil microbial populations, which improves soil organic carbon– a direct indicator of soil health. Thus mulching is one of the effective crop residue management practices that could be used to conserve or enhance soil fertility. Sharma *et al*. (2009) [19] reported higher organic carbon, available soil nutrients *viz.* N, P and K and lower soil pH due to application of Leucaena leaves as soil mulch as compare to no mulch (Table 4).

Table 4: Soil chemical properties as influenced by dose and timing of application of Leucaena mulch

Treatments	Organic carbon (%)	Total N (%)	Avl. P (ppm)	Avl. K (ppm)	Soil pH
Level of mulch (t ha^{-1})					
0	0.55	0.05	29.0	160	6.8
2	0.60	0.06	30.0	163	6.7
4	0.68	0.06	30.5	168	6.5
6	0.72	0.07	30.8	169	6.4
Days after incorporation					
0	0.55	0.05	28.5	161	6.6
15	0.59	0.05	30.2	162	6.6
30	0.60	0.06	30.3	163	6.5
45	0.60	0.06	30.3	165	6.4

Source: (Sharma *et al*. 2009) [19]

4. Crop residue as compost materials

The harvest refuses which includes straws, stubble, stover, haulms of different crops and crop remains from thrashing sheds or that are discarded during crop processing can be used as bedding for animals and a substrate for composting. Thus recycle considerable amount of plant nutrients and have greatest potential to be used as organic fertilizer.

Green manuring

Green manure crops are those crops, that are grown either *in–situ* or *ex–situ* and to be turned in to the soil to improve physical, chemical and biological properties of soil (FAO 2011)." Types of green manuring

1. *In–situ* green manuring– When green manure crops are grown in the field itself either as a pure crop or as intercrop with the main crop and buried in the same field, it is known as *in–situ* green manuring e.g. sunhemp, dhaincha, pillipesara, shervi, urd, mung, cowpea, berseem, senji, etc.

2. *Ex–situ* green manuring– It refers to turning of green leaves and tender twigs of shrubs and trees into the soil, collected from bunds, waste lands and nearby forest area e.g. glyricidia, wild dhaincha, karanj etc.

Potential green manure crops

1. *Sesbania aculeata* (Dhaincha)

Sesbania aculeata is most preferable green manure crop among the farmers (Fig. 2). It is a quick growing, succulent green manure crop which can be sown using about 40–50 kg seed ha^{-1} and can be incorporated at about 6 to 8 weeks after sowing. The green biomass yield of dhaincha is about 20–30 t ha^{-1}. It can fix about 96–135 kg N ha^{-1} through biological N fixation.

2. *Sesbania rostrata* (Sesbania)
Sesbania rostrata bears nodules both on stem and root and thrives well under waterlogged condition. The normal seed rate for sowing is about 30–40 kg ha^{-1}. It can produce about 15–20 t ha^{-1}green matter and fixes about 80–110 kg biological N ha^{-1}. Pruning of *Sesbania* leaves grown on bunds would be a source of readily available plant nutrients.

3. *Crotalaria juncea* (Sunhemp)
Sunhemp as a green manure crops are generally grown during rainy season. The normal seed rate for sowing is about 35 kg ha^{-1} and incorporated in soil at about 30–45 days crop age. It can fix about 95–100 kg atmospheric N ha^{-1}.

4. *Vigna umbellata* (Rice bean)
Rice bean is a quick growing legume green manure crop and mostly grown in north–eastern part of India (Fig. 2). Normal seed rate for sowing is about 35 kg ha^{-1} as a green manure crop. The leaves are broad in size and contain almost 3.1% N.

5. *Leucaena leucocephala* (Subabul)
Subabul is a multipurpose tree is used for fuel wood, lumber, animal fodder, and green manure. It contains about 3–4% N and fixes about 260–320 kg N $ha^{-1}year^{-1}$. The incorporated leaves of *Leucaena* decompose quickly, and provide a rapid influx of nutrients in soil.

Source: (Yadav *et al*. 2017) [25]

Fig 2: *Sesbania aculeata* and *Vigna umbellata* green manure crops

Nutrient composition of green manure crops
Green manure crops contain several essential plant nutrients and upon decomposition release nutrients quickly (Table 5). Green manure crops also provide large quantities of N to the soil through biological N fixation. The amount of N fixation depends on species of leguminous green manure crops (Table 6).

Table 5: Nutrient compositions of important green manure and green leaf manure crops

Crop	Nutrient content (%) on dry weight basis		
	N	P	K
Green manure crops			
Sesbania aculeata	3.3	0.7	1.3
Crotalaria juncea	2.6	0.6	2.0
Sesbania speciosa	2.7	0.5	2.2
Tephrosia purpurea	2.4	0.3	0.8
Green leaf manure crops			
Pongamia glabra	3.2	0.3	1.3
Glyricidea maculeata	2.9	0.5	2.8
Azadirachta indica	2.8	0.3	0.4

Source: (Sangma 2017) [18]

Table 6: Biological nitrogen fixation by *in-situ* and *ex-situ* green manurings crops

Green manure crops	Biological N fixation (kg ha^{-1})	References
***In-situ* green manuring crops**		
Sesbania aculeata	96-135	(Masood and Bano 2016) [13]
Sesbania rostrata	83-109	(Masood and Bano 2016) [13]
Crotalaria juncea	95-100	(Mendonça *et al*. 2017) [14]
Vigna unguiculata	60-65	(Keston *et al*. 2017) [9]
Vigna radiata	35-50	(Hayat et el. 2008) [6]
***Ex-situ* green manuring crops**		
Leucaena leucocephala	260-320	(Rajendren and Mohan 2014) [17]
Pongamia glabra	200-210	(Rajendren and Mohan 2014) [17]
Gliricidia sepium	105-110	(Mendonça *et al*. 2017) [14]

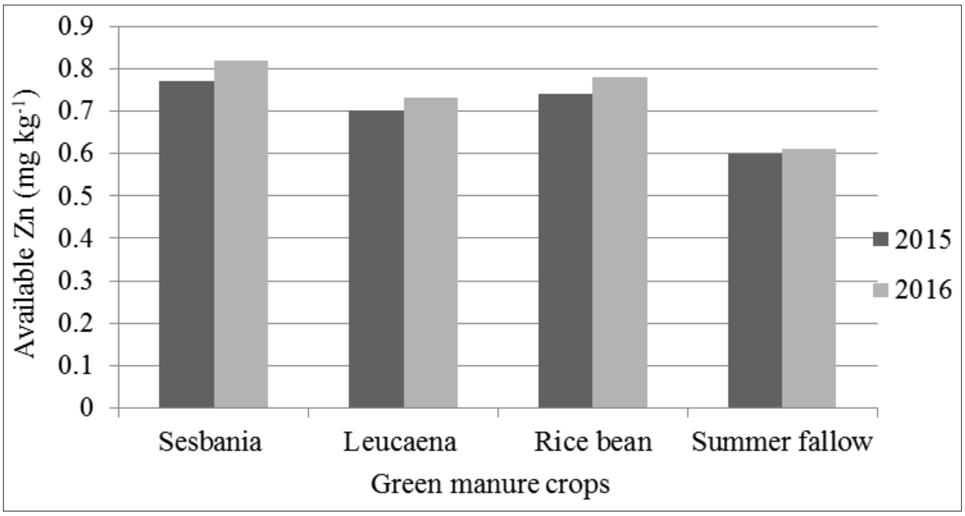
Divergent green manuring practices
1. Incorporation before sowing/planting of main crops
In this method, green manure crops are grown and incorporated in same field before sowing/transplanting of main crops. Yadav *et al.* (2017) [25] reported that *in–situ* incorporation of *Sesbania aculeata* accumulated highest N and it was significantly higher than *Leucaena leucocephala* and statistically at par with *Vigna umbellata* while P accumulation with *Sesbania aculeata* was significantly higher than *Vigna umbellata* and *Leucaena leucocephala*. (Table 7).

Zn accumulation with *Sesbania aculeata* was statistically similar with *Vigna umbellata* while *Vigna umbelata* recorded significantly higher Mn accumulation than *Sesbania aculeata*. In the same experiment, available Zn content of soil at harvest of rice also increased over initial status of soil (0.62 mg kg^{-1}) and summer fallow treatments due to *in–situ* green manuring (Fig. 3).

Table 7: Total macro and micro nutrients accumulations (root + shoot) of green manure crops under basmati rice–wheat cropping system

Treatment	N (kg ha^{-1})		P (kg ha^{-1})		Zn (g ha^{-1})		Mn (g ha^{-1})	
	2015	2016	2015	2016	2015	2016	2015	2016
Sesbania aculeata	143.9	150.4	16.2	18.6	360.0	392.7	540.1	609.5
Leucaena leucocephala	100.9	102.3	7.1	7.3	74.5	85.8	108.9	120.8
Vigna umbellata	128.4	148.8	14.6	17.7	331.0	396.8	1070.1	1112.0
SEm±	3.22	3.05	0.78	0.66	9.62	7.45	18.20	17.91
LSD (*P*=0.05)	12.65	11.97	3.06	2.63	37.8	29.2	71.47	70.35

Source: (Yadav *et al*. 2017) [25]



Source: (Yadav *et al*. 2017) [25]

Fig 3: Effect of green manuring in standing wheat residue on soil available zinc under basmati rice–wheat cropping system

In this context, Aulakh *et al*. (2001) [2] also observed significant improvement in soil mineral nitrogen as a result of green manure crops chopped with wheat residue. Integrated application of wheat straw with sesbania green manure increases agronomic nitrogen use efficiency and also improves negative apparent nitrogen balances as observed by Sharma and Prasad (2008) [20] under rice–wheat cropping system.

2. **Intercropping with main crops (sowing/planting with main crops)**

Green manure crops can often be planted along with row crops, especially corn, sorghum and millet without decreasing the population of the main crop. The green manure crop is either cut and left on the soil surface as mulch or knocked down using selective herbicides at 45-50 days after sowing.

3. Intercropping with main crops while planting at end of growing season

Green manure crops can often be intercropped with widely spaced crops like cotton, castor etc. at end of the growing season to utilize residual soil moisture and with the idea that their major growth would occur during the dry season, thereby using land that would not ordinarily be under cultivation.

4. Multi–year fallow system

Wherever multiple year fallows or shifting agriculture is used, green manures can be planted on land the first year it is to go fallow. Thus the period of fallow can be cut to one year instead of three or more years.

5. Use of green manure crops in conjunction with alley cropping

Alley cropping is an agro–forestry practice where crops are grown between lines of trees or shrubs that are managed and spaced at regular intervals in cropland. Alley cropping with green manure crops has received much research attention and is regarded as having promise for solving problems of declining soil fertility in situations where farmers cannot afford to use inorganic fertilizers.

6. *Ex–situ* green manuring/Green leaf manuring

In this method, green manure crops are grown in one place and then transported to another area where the crop is to be incorporated into the soil. Green leaves and tender twigs are collected from outside the field and incorporated in to soil where needed.

Conclusion

Crop residues and green manure contain a significant quantity of nutrients which can be used in different ways for recycling of organic matter to improve soil health and fertility under different land use systems. As a general practice, most of the crop residues are burnt for the purpose of cleaning & preparing the field for the sowing of subsequent crops. Also due to intensification of cropping system and availability of fertilizers farmers are reluctant and consider green manuring as a wasteful activity which did not yield any economic advantage to them. Concerted efforts and awareness among the farming community is required to make them realize the importance & role of crop residues and green manure crops in nutrient recycling and soil health benefits towards achieving the task of sustainability in crop production and overall input use efficiency. It is also evident from different studies reviewed in this paper that efficiency of crop residues in terms of nutrient recycling and decomposition in soil can be improved if green manured materials are added/mixed with them through divergent green manurings practices.

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