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DECOMPOSITION AND NITROGEN MINERALIZATION OF SHREDDED COTTON STALKS AND EFFECT ON SOIL MICROBES AND SUCCEEDING SWEET CORN (*Zea mays Saccharata* L.)

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India ranks first in the world in area under cotton cultivation (12.77 million ha). It is also the largest cotton producer in the world with 28.50 million bales followed by China (27.25 million bales), United States (20.02 million bales), Brazil (12.00 million bales) and Pakistan (8.00 million bales) (www.agricoop.nic. in). In Telangana State, it was cultivated in an area of 2.12 million ha during 2019-20 and it stood third in the country with a production of 55.61 million tonnes (www.agri. telangana.gov.in). In India and Telangana, cotton crop generates nearly 25-30 MT and 4.0-5.0 MT of stalks, respectively with an average stalk production of 2-3 t ha^{-1} (Ramanjaneyulu *et al*., 2021) and are rich in nutrients having 51.0, 4.9, 1.0, 0.61, 0.08, 0.43 and 0.12 % C, H, N, K, P, Ca and Mg, respectively (Anil *et al*., 2004). Majority of the farmers resort to burning of the cotton stalks *in-situ* to clear the field for the next crop which leads to environmental pollution through the emission of greenhouse gases and adversely affects the soil microbial population. Cotton stands third (9.8) in terms of air pollution emission intensity (PM2.5) next to sugarcane (12.0), maize (11.2) followed by rice (9.3) and wheat (8.5) (TERI, 2019). Instead of burning, these stalks can be shredded and returned to the soil for improving the soil and crop productivity apart from using for the purpose of livestock feed, composting, biofuels (biochar and bio-oils) and mulching etc.

Owing to the reduced duration of Bt cotton compared to its non-Bt counterpart, farmers are growing irrigated dry crops such as sweet corn, sesame, vegetables, watermelon, and green gram after Bt cotton, depending on the water availability and soil type. Cotton + green gram – maize was found to be profitable cropping system in Telangana State (Pragathi Kumari *et al*., 2018). Maize crop requires large quantity of nutrients. Sweet corn is of short duration and hence gaining popularity in peri-urban areas. It accounts for 8 and 25% of the world's area and production, respectively. Several research studies indicated that incorporation of the crop residues enhances the soil fertility and productivity over long run (Benbi *et al*., 2012; Ghosh *et al*., 2016; Singh *et al*., 2016; Liu *et al*., 2017). Decomposition rates and nutrient release patterns are controlled by both biotic and abiotic factors, the most important of which is residue quality (Teklay *et al*., 2007). Of late, machinery like Multi crop shredder, Terminator, Rotavator, Cotton stalk choppers were developed for cotton residue shredding for enhancing the soil contact upon incorporation. Keeping in view of these, the present study was taken up to investigate the decomposition, nitrogen mineralization of shredded cotton stalks and its impact in the succeeding sweet corn and soil properties.

The field experiment was conducted at college farm, Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad, Telangana State during *rabi*, 2020-2021. It was laid out in randomized complete block design with factorial concept and replicated thrice on a sandy clay loam soil. The treatments consisted of RM_1- cotton stalks incorporated; RM_2- No incorporation; F_1- Control (no fertilizer); F_2-75% RDF (150:45:37.5 NPK kg ha^{-1}); F_3-100% RDF (200:60:50 NPK kg ha^{-1}); F_4-125% RDF (250:75:62.5 NPK kg ha^{-1});F_5-150% RDF(300:90:75 NPK kg ha^{-1}). The cotton stalks which collected from preceding crop were shredded with Tractor operated cotton shredder and were incorporated @ 5 t/ha as per the treatments before sowing of the sweet corn. The seeds of 'Sugar 75' variety were dibbled @ 1 seed $hill^{-1}$ at a spacing of 60 cm x 20 cm and 4-5 cm depth in conventionally tilled soil. The gross and net plot sizes were 9.6 x 3.0 m^2 and 8.4 x 2.6 m^2, respectively. Entire phosphorus and potash were applied as basal. Nitrogen was applied as per schedule *i.e.*,1/3rd N each at 20, 40 and 60 DAS. The crop was raised with need based irrigations following the other recommended practices for the region. Cobs were harvested at 98 DAS. Data on the green cob yield and stalk yield was recorded.

Soil samples were drawn before sowing, at 45 DAS and harvest and analyzed for the following parameters by the standard procedures.

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S. No	Parameter	Initial value	Method adopted
1.	pH (1:2.5 soil: water)	7.78	Glass electrode pH meter (Jackson, 1967)
2.	EC (dS m^{-1}) at 25 ^{0}C (1: 2.5 soil: water suspension)	0.37	Digital Conductivity Bridge Method (Jackson, 1967)
3.	Organic Carbon (%)	0.34	Chromic Acid Titration Method (Walkley and Black, 1934)
4.	Available nitrogen (kg ha^{-1})	201	Alkaline Potassium Permanganate Method (Subbaiah and Asija,1956) Kelplus-Classic Dx
5.	Available phosphorus (kg ha^{-1})	28	Olsen's extractant method (Olsen *et al*., 1954)
6.	Available potassium (kg ha^{-1})	370	Neutral normal ammonium acetate method using flame photometer (Jackson, 1967)
7.	Bulk density (g cm^{-3})	1.38	Core sampler method. Keen and Raczkowski, 1921
8.	Water holding capacity (%)	16.02	Keen cup method. Keen and Raczkowski, 1921
9.	Ammonical and nitrate nitrogen	-	Potassium chloride titration method Keeney and Nelson, 1982
10.	Total carbon in cotton stalks	-	Loss on ignition method Heiri and Lotter, 2001)
11.	Total nitrogen in cotton stalks	-	AOAC, 1995
12.	Cellulose in cotton stalks	-	Acid detergent fibre method. Updegroff (1969).
13.	Lignin in cotton stalks	-	Acid detergent lignin method Georing and Vansoest 1975.
14.	Soil moisture content (%)	-	Gravimetric method

The C/N ratio was determined by dividing the total carbon value with the total nitrogen content. The ratio of weight of total carbon to total nitrogen is called Carbon/Nitrogen ratio.

$$\text{C/N ratio} = \frac{\text{Total carbon content}}{\text{Total Nitrogen content}}$$

Colony forming units of bacteria (X 10^5 CFU g^{-1}), fungi (X 10^4 CFU g^{-1}) and actinomycetes (X 10^3 CFU g^{-1}) were determined by serial dilution and plating on selective media. The replicates of the inoculated agar plates were incubated for 2 days at 37 ^{0}C for bacteria, 5 days for fungi at 28 ^{0}C and 7 days for actinomycetes at 30 ^{0}C after which the counts were taken.

Cotton stalks C/N ratio

Initial C/N ratio of cotton stalks used in the present study was 50.5:1, at 45 DAS it was reduced to 37.1:1 and at harvest (100 days) reached to 31.5:1 (Table 1). It is generally accepted that residues with a wide C/N ratio decompose more slowly than those with a narrow C/N ratio (Pam and Papendick, 1978). For every 100 g of residue decomposed by microorganisms, approximately 0.8 g of nitrogen is required (Henriksen and Breland, 2002) and the appropriate C/N ratio for soil microorganisms to decompose organic materials is approximately 25-30:1 (Kochsick and Knops, 2013). In the present study, the C/N ratio reached to this ratio by ~ 100 DAS. Reinertsen et al. (1984) and Singh and Rengel (2007) reported that 1.13% N straw decomposed 2.3 and 1.6 times faster than 0.18 and 0.79% N straws, respectively. Studies have shown that when the nitrogen content of the straw is less than 1.2% inorganic nitrogen will be fixed into organic compounds, when the nitrogen content exceeds 1.5% it is not necessary to supplement the external nitrogen in the process of straw decomposition (Mubarak and Rosenani, 2003).

Cellulose and lignin content in cotton stalks

Initial cellulose content in the cotton stalks was 34%, at 45 DAS it was reduced to 9.4% and to 8.6% at harvest. Initial lignin content in cotton stalks was 22%, reduced to 18.9 and 17.7% at 45 DAS, harvest stage, respectively (Table 1). Cotton stalks are mainly composed of cellulose, hemicellulose, lignin and soluble sugars (Chen, 2007). The decomposition of crop residue returned to the field is divided into two stages. The first stage is the rapid decomposition stage, in which the organic materials such as cellulose, hemicelluloses and soluble sugars are mainly decomposed and the soil microorganisms are more diverse and show higher activity (Zhang and Wang,

Table 1. C/N ratio, cellulose, and lignin content of cotton stalks

Stage	Treatment	Total C	Total N	C/N ratio	Cellulose (%)	Lignin (%)
INITIAL		**42.9**	**0.85**	**50.5**	**34.0**	**22.0**
45 DAS	RM_1F_1	39.4	0.83	47.5	15.1	20.3
	RM_1F_2	41.8	0.93	44.9	13.3	19.1
	RM_1F_3	37.7	0.88	42.8	10.5	19.1
	RM_1F_4	39.4	0.95	41.5	10.2	19.0
	RM_1F_5	37.1	1.00	37.1	9.4	18.9
Harvest (98 DAS)	RM_1F_1	40.6	0.90	45.1	10.1	19.1
	RM_1F_2	42.9	1.10	39.0	9.8	18.3
	RM_1F_3	38.9	1.14	34.1	9.2	18.3
	RM_1F_4	38.3	1.12	34.2	8.8	18.1
	RM_1F_5	36.5	1.16	31.5	8.6	17.7

2000; Jiang *et al.,* 2001 and Jiang *et al*., 2002) the second stage is the slow decomposition stage, in which lignin and other substances that were not decomposed or were minimally decomposed which can last 2-3 years or longer (Dai, 2009). Therefore, cotton stalks incorporated cannot be completely decomposed in one crop season.

Bacteria account for 70-90% of all soil microorganisms and are the most active factor in soil, playing an important role in the decomposition of cellulose in residues (Xu *et al*., 2010). Lignin is known to be a recalcitrant substance, highly toxic and resistant to microbes (Mellilo *et al*., 1982; Chaves *et al*., 2005 and Hofmann *et al*., 2009). Only relatively few microorganisms can degrade lignin and these are exclusively aerobic. Many workers have found that increasing the lignin concentration reduces the decomposition rate and nutrient release from plant residues and also enhances nutrient immobilization, especially N (Aber and Mellilo, 1982., Aber *et al*., 1990 and Tian *et al*., 1992). Muller *et al.* (1988) found that the lignin concentration was a much better predictor of the residue decomposition rate than N concentration. Crop residues may contain some organic compounds that can make soil N less plant available. For example, high lignin contents in decomposing residue may decrease soil nitrogen availability by binding N to aromatic rings, forming compounds that are resistant to further decomposition (Bending and Turner, 1999. Schmidt *et al.,* 2004 and Wang *et al.,* 2004). However, the excessive application of nitrogen fertilizer will inhibit the activity and chemical stability of lignin-decomposing enzymes in the soil, thereby delaying the decomposition of straw (Arcand *et al*., 2014., Magill and Aber, 1998).

Nitrogen mineralization

The ammonical ($NH4^+$-N) and Nitrate -N ($NO3^-$-N) of the surface soil (- 15 cm) in the cotton stalks incorporated plots was significantly increased (8.8 and 9.8%, respectively) compared to their removal at 100 days i.e., harvest of the sweet corn (Table 2). Application of 150 % RDF resulted in significant improvement in $NH4^+$-N and $NO3^-$-N in soil over the 100% RDF, 75% RDF and control. Mineral N ($NH4^+$-N and $NO3^-$-N) is released from soil organic matter, crop residue by microbial decomposition, mineralization and nitrification regulated by soil moisture, temperature, and residue quality in terms of C/N ratio, lignin content (Nunez *et al*., 2001; Palm *et al*., 2001; Bolger *et al.,* 2003). Muhammad *et al. (*2011) conducted an incubation study for 84 days with different crop residues and found that immobilization of N occurred with sugarcane (C/N- 142:1), maize (C/N- 86.9:1) and sorghum (C/N- 57.1:1) but cotton had modest effect with C/N- 29.2:1 while lucerne with narrow C/N (12.1:1) had positive balance of mineral N at the end of incubation period. These findings lend support to our results wherein positive balance of mineral N was observed with cotton residues by the end of crop season (~100 days).

Microbial population

Microbial population count (bacteria, fungi and actinomycetes) was recorded from samples collected from the surface (0-15 cm) at 30, 60 DAS and harvest of the sweet corn (Table 3). The bacterial, fungal and actinomycetes population was significantly higher in the treatment where the residues were added than in the residue removal. The latter treatment showed relatively lower microbial count and was virtually unchanged throughout the study period. Plant residues can serve as a source of nutrients which is made available to the plants only after microbial activity (Beri *et al*., 1995). Incubation study conducted by Muhammad *et al*. (2011) also demonstrated that the MBC and MBN increased by 15% in cotton amended soil compared to unamended soil after 84 days. Similarly, the fertilized plots (75, 100, 125 and 150% RDF) showed higher microbial count over unfertilized plots. The population of actinomycetes was the higher as compared to bacteria and fungi, because slightly alkaline conditions favour actinomycetes growth. Many research findings show that long-term burning decreased the microbial population of the soil permanently, severely declining the bacteria population involved in nitrification. It takes several months to five years to recover that activity (Tisdall, 1992). Declining microbes in the soil affect the sequestration of carbon in the soil and lead to decline in soil fertility. Beri *et al*. (1992) found that soil treated with crop residues inhabited 5-10 times more aerobic bacteria and 1.5 to 11 times more fungi than in soil where residues were either burnt or removed. Azmal *et al.* (1997) observed that total C and N in the soil microbial biomass increased immediately after residue incorporation under aerobic conditions, reached maximum values after one week and decreased thereafter. However, the residues with wider C/N ratio need simultaneous application of $NH4^{+}$-N for quick growth of microbes (Nugroho and Kuwatsuka, 1992).

Yield

There was no significant effect of cotton stalks incorporation in green cob and stalk/fodder yield (t ha^{-1}) over residue removal (Table 2). Our results are in similarity with Gursoy *et al.* (2010) results of three years field experiment indicated that chopping and retaining the cotton stalks had no significant effect on grain yield of wheat. Davari *et al*. (2012) also reported that rice yields were unaffected by the residue incorporation in first year of study. Multi-year fold experiments have illustrated that the cumulative N recovery of organic residues fitted well to a first-order kinetic model (Ueno *et al*., 2001) and the curve appeared to reach a steady state after three years of cultivation (Chalk *et al*., 2013).

Sprunger *et al*. (2019) compared the maize yields in a long-term residue management (10+ years) in Kenya and found that the residue with low C/N ratio (legumes) significantly enhanced the maize yields compared to maize stover with wider C/N ratio. The mineralizable carbon was enhanced by 57% in legume residue applied plots than that of maize stover.

In the present study, cotton stalks (shredded) with wider C/N ratio (50.5:1) were used. The succeeding sweet corn crop was harvested at 98th DAS. At 45 DAS and harvest, the C/N ratio of the cotton was 37.1:1 and 31.5:1, respectively. It is apparent that the ratio was getting narrowed down with advancement of time.

The corresponding C/N ratio of the soil were 12.1:1, 11.9:1 and 11.6:1 at initial, 45 DAS and harvest, respectively (Table 4). It can also be observed that there was a positive balance of $NH4^{+}$-N and $NO3^{-}$ -N pools in cotton stalks applied plots at the end of the crop season (Table 2) indicating the N-mineralization,

Table 2. Effect of cotton stalks incorporation and fertility levels on N mineralization (NH_4^+-N, NO_3^- -N) in soil and yield of sweet corn

Treatment	NH_4^+-N (mg/kg of soil)	NO_3^- -N (mg/kg of soil)	Green cob yield (t ha^{-1})	Green fodder yield (t ha^{-1})
Residue Management (RM)				
RM_1 : Cotton stalks incorporation	22.1	13.4	25.0	28.5
RM_2 : No incorporation	20.3	12.2	24.7	28.4
SEM ±	0.6	0.3	0.6	0.2
CD (P = 0.05)	1.6	1.0	NS	NS
Fertility Levels (F)				
F1 : Control (No fertilizers)	18.7	12.6	17.9	23.0
F2 : 75% RDF	21.4	14.8	24.1	27.5
F3 : 100% RDF	22.5	15.3	25.2	28.9
F4 : 125% RDF	23.8	17.7	28.4	31.3
F5 : 150% RDF	25.2	18.5	28.9	31.6
SEm ±	0.7	0.5	0.9	0.4
CD (P = 0.05)	2.1	1.6	2.6	1.2
Interaction (RM x F)				
SEM ±	1.2	0.8	1.2	0.6
CD (P = 0.05)	NS	NS	NS	NS
Initial	54.3	34.1	-	-

Table 3. Microbial population of soil as influenced by incorporation of cotton stalks and fertility levels in succeeding sweet corn

Treatment	Bacteria (x 10^5 CFU g^{-1}dry soil) of soil			Fungi (x 10^4 CFU g^{-1}dry soil)			Actinomycetes (x 10^3CFU g^{-1}dry soil)		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Residue Management (RM)									
RM_1: Cotton stalks incorporation	13.7	11.7	11.4	7.4	9.3	9.1	24.9	27.4	21.9
RM_2: No incorporation	10.4	8.8	8.7	4.7	5.9	5.8	20.0	22.0	17.6
SEm ±	0.3	0.3	0.2	0.2	0.2	0.2	0.6	0.6	0.5
CD (P = 0.05)	0.9	0.7	0.7	0.5	0.7	0.7	1.7	1.8	1.5
Fertility Levels (F)									
F_1: Control	9.5	8.1	7.9	4.3	5.4	5.3	18.3	20.2	16.1
F_2: 75% RDF	12.0	10.2	10.0	6.0	7.5	7.4	22.8	25.1	20.1
F_3: 100% RDF	12.7	10.8	10.6	6.2	7.7	7.6	23.3	25.7	20.5
F_4: 125% RDF	13.0	11.1	10.8	6.8	8.5	8.4	23.8	26.2	21.0
F_5: 150% RDF	13.2	11.2	11.0	7.0	8.8	8.6	24.0	26.4	21.1
SEm ±	0.5	0.4	0.4	0.3	0.4	0.4	0.9	1.0	0.8
CD (P = 0.05)	1.4	1.2	1.2	0.9	1.1	1.1	2.7	2.9	2.3
Interaction (RM x F)									
SEm ±	0.7	0.6	0.6	0.4	0.5	0.5	1.3	1.4	1.1
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial		10.8			3.9			12.6	

Table 4. Soil properties as influenced by incorporation of cotton stalks and fertility levels

Treatments	pH	EC (dS m^{-1})	OC (%)	Bulk Density (g cm^{-3})	WHC (%)	Soil C/ N Ratio	
						45 DAS	Harvest
Residue Management (RM)							
RM_1: Cotton stalks incorporation	7.75	0.365	0.35	1.32	20.1	11.86	11.57
RM_2: No incorporation	7.74	0.367	0.34	1.33	19.2	11.62	11.44
SEM ±	0.2	0.01	0.02	0.04	0.5	0.17	0.12
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS
Fertility Levels (F)							
F_1: Control (No fertilizers)	7.76	0.368	0.32	1.34	18.8	11.95	11.81
F_2: 75% RDF	7.76	0.366	0.33	1.33	19.2	11.91	11.56
F_3: 100% RDF	7.75	0.368	0.35	1.32	19.5	11.60	11.42
F_4: 125% RDF	7.79	0.371	0.35	1.31	20.4	11.60	11.38
F_5: 150% RDF	7.78	0.373	0.36	1.31	20.9	11.59	11.35
SEM ±	0.07	0.01	0.03	0.06	0.84	0.26	0.20
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS
Interaction (RM x F)							
SEM ±	0.10	0.02	0.02	0.11	1.18	0.37	0.28
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS
Initial	7.78	0.368	0.34	1.38	16.0	12.08	

Table 5. Soil properties as influenced by incorporation of cotton stalks and fertility levels

Treatment	Soil temperature (°C)		Soil moisture (%)		Available NPK		
	45 DAS	Harvest	45 DAS	Harvest	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
Residue Management (RM)							
RM_1: Cotton stalks incorporation	21.3	39.2	6.3	2.5	220	34	385
RM_2: No incorporation	21.6	39.4	6.1	2.3	213	29	373
SEm ±	0.4	0.9	0.16	0.06	5.6	0.3	3.2
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS
Fertility Levels (F)							
F_1: Control (No fertilizers)	21.6	39.4	5.58	2.08	196	26	367
F_2: 75% RDF	21.6	39.3	6.08	2.32	205	28	377
F_3: 100% RDF	21.6	39.3	6.10	2.35	210	29	381
F_4: 125% RDF	21.4	39.2	6.11	2.37	215	30	385
F_5: 150% RDF	21.3	39.2	6.13	2.50	218	31	386
SEm ±	0.9	1.0	0.26	0.10	8.8	0.5	5.2
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS
Interaction (RM x F)							
SEm ±	0.7	2.0	0.37	0.13	5.5	0.2	7.34
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS
Initial	27.9		4.98		201	28	370

but it might have not been in the magnitude to effect yield enhancement. Hence, it can be inferred from the above discussion that the yield advantage due to incorporation of residues with wide C/N ratio may be realized on long-term application. Our results strongly corroborate the findings of Sakala *et al*. (2000), Dam *et al*. (2005), Seyed *et al*. (2014), Almaz *et al*. (2017) and Ding *et al*. (2019).

The green cob and stalk/fodder yield was found to be increased with increased fertility levels from 0 to 150% RDF. The maximum green cob yield was produced with the application of 150% RDF, which was on par with 125% RDF. Whereas lower green cob yield was obtained with no fertilizer application. Higher amounts of 'N', 'P' and 'K' improves physiological processes, plant metabolism and development resulting in increased yield. These results are in accordance with Zeidan *et al*. (2006), Mukhtar *et al.* (2011) and Dechassa *et al.* (2014), Sharifi and Namvar (2016) and Shrestha *et al*. (2018), who found that applying a high dose of N produced the highest cob yield. Enhanced cob yield at higher NPK levels might be due to the lower competition for nutrients which leads to more canopy of plant contributing higher photosynthetic activity to accumulate more biomass. However, there was no significant interaction effect between residue management and fertility levels for yield of sweet corn.

Soil properties

The soil properties at harvest of sweet corn such as pH, electrical conductivity, organic carbon, bulk density, water holding capacity, moisture content, temperature, available NPK, C/N ratio were not influenced by the cotton stalk incorporation as well as NPK levels (Tables 4 & 5).

From the results of this study, it can be concluded that incorporation of shredded cotton stalks@5 t/ha had positive influence on the soil microbial population and nitrogen mineralization but could not enhance the yield and soil parameters. Application of 25% additional NPK to the recommended dose produced higher sweet corn yield.

Authors' contribution

Conceptualization of research work and designing of experiments (MMR); Execution of field/lab experiments and data collection (KBR); Analysis of data and interpretation (KBR, BP, TS); Preparation of Manuscript (KBR, BP, MMR)

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