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Performance Indices of a Combined Tillage Machine for the Incorporation of Leguminous Green Manure at Appropriate Depth

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ABSTRACT

Background: The decomposition rate of biomass depends significantly on soil properties and on the design of the machine used for incorporation. Well-chopped biomass, incorporated in a productive zone with uniform mixing, gives better results instead of placing longer stalks on or near the field surface.

Methods: In the field experiments conducted during 2017 and 2018, interaction of soil and biomass, placed at various depths in sandy loam soil, was studied 10, 20, 30, 40, 50, 60 and 90 days after incorporation (DAI). Further, mechanical incorporation of green manure crop with innovative two-bottom combined tillage machine, namely biomass incorporator, was studied at different levels of soil type, plant height, forward speed and rotor speed.

Result: The depth range of 70-140 mm was found most appropriate for incorporation to achieve a higher decomposition rate. Plant stem of 50 days old dhaincha (*Sesbania aculeata*) crop decomposed by 13.0, 31.5, 29.25, 24.25 and 22.05% at depth range 0-70 (D1), 70-140 (D2), 140-210 (D3), 210-280 (D4) and 280-350 (D5) mm, respectively 10 DAI. About 55% of the biomass, incorporated at depth range D2, got decomposed 40 DAI. The average depth of placement of biomass with biomass incorporator ranged between 92 and 131 mm. The soil pulverization index and crop mixing index with the machine varied from 3.58 to 30.65 mm and 93.62 to 98.05%, respectively. The surface profile coefficient with the machine ranged between 24.2 and 50.6 mm. The efficient mixing of the biomass into the soil with thorough coverage of pulverized soil was achieved with rational field undulation.

Key words: Biomass incorporator, Combined tillage machine, Green manuring, Legume crops, Mixing index.

INTRODUCTION

Overuse of synthetic nitrogen (N) fertilizer to enhance agricultural production is threatening the environment (Meena *et al*., 2018), causes accumulated side effects on human and animal health and increases agricultural production cost (Bahnas and Khater, 2015; Cassou, 2018). This approach has resulted in gradual degradation of soil organic matter because of the breakdown of stable soil aggregates and decomposition of organic matter (OM). Consequently, soil health is being deteriorated in terms of reduction in water holding capacity of soils, surface and ground-water pollution, formation and concentration of mineral salts which leads to compaction layer, soil acidity and multiple nutrient deficiencies (Gill *et al*., 2008; Meena *et al*., 2013, Massah and Azadegan, 2016; Singh, 2018).

Global concerns on agricultural sustainability and ecological stability have revived the interest of farmers and research workers to opt for non-chemical sources of plant nutrients *i.e.* organic manures (Eagan and Dhandayuthapani, 2018). Green manuring is an effective and low cost technology which replenishes soil health naturally and also helps in minimizing the cost of chemical fertilizers while safeguarding productivity. Studies across the globe have established the benefits of green manures on soil physicochemical and biological health (Meena *et al*., 2018; Sah, 2020; Sarkar *et al*., 2020). The addition of organic amendments into soils, particularly green manure, has potential to control weeds and soil-borne diseases and to disrupt the life cycle of agriculture pest (Kumar *et al*., 2014; Varma *et al*., 2017).

Well-chopped and uniformly mixed biomass, incorporated in productive zone, gives better results instead of placing longer stalks on or near the field surface. Temperature, moisture and soil texture are important determinates of patterns of particular biomass decomposition. Since these factors vary through a soil profile, decomposition rates also vary with depth in a soil profile (Gill and Burke, 2002). As the depth of placement has significant effect on decomposition rate, it is one of the important deciding factors while designing machinery for biomass incorporation. The present on-farm study was

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conducted to determine suitable depth of placement of green manure crop, widely cultivated in northern India, so as to accomplish accelerated decomposition rate. Conventional mould board plough handles significantly high amount of soil mass but inverts it on the field surface with minimum breakup. Further, no chopping of plant biomass result in improper or partial coverage of biomass with soil. Moreover the field is left uneven with big clod formation (Verma *et al*., 2020). Multiple operations of disc harrow and leveler after operation of mould board plough breaks the soil clods, show better incorporation efficiency and helps in leveling of fields but these combinations are not feasible in terms of direct energy utilization and higher cost of operation.

Rotary plough or rotavator is better from tillage point of view but it is poor to moderate from incorporation efficiency point of view because of lower depth of penetration and handling of lesser amount of soil mass. Lesser amount of soil mass results in partial coverage and depth of placement of biomass is only 0-50 mm. Application of rotavators in crop production systems, demanding the manipulation of the soil at deeper depths, appears to be hindered by the perceived excessive energy requirement. Owing to this, commercially available rotavators are being designed for shallow tillage (Marenya, 2015). A tractor operated combined tillage machine namely, biomass incorporator (Verma, 2019) was developed at Punjab Agricultural University, Ludhiana for efficient burying of green manure crop. The primary soil cutting and lifting mechanism of the machine is similar to the conventional mould board plough but integration of soil ripper in the machine crumbles the soil clods and spreads it thoroughly. In the present study, roughness or unevenness of the field after operation of the machine was also studied.

MATERIALS AND METHODS

Determination of suitable placement depth for maximum decomposition rate of biomass

A sub-experiment was conducted to find suitable depth of placement of the biomass in soil so as to obtain maximum decomposition rate of biomass. For this purpose litter bag or nylon mesh bag technique was used (Schomberg *et al*., 1994; Beare *et al*., 2002; Virappa, 2010; Solly *et al*., 2014). According to Kumar and Goh (2000), litter bag method was developed to explain decomposition in undisturbed soil systems and because of its simplicity was extended to arable systems, in which plant residues are normally admixed with the soil by tillage practices.

A litter bag study for determination of suitable depth of placement of biomass was conducted under experimental conditions. In this method, nylon bags of size 12×15 cm having mesh size of 1×1 mm were used. Bags having small mesh size were used so that weight loss of biomass enclosed in mesh bags is attributed to microbial decomposition only and there is no loss of biomass particles through mesh openings. The soil used in the experiment was sandy loam type having composition of sand, silt and clay as 70.1, 14.9 and 15.0%, respectively with moisture content of 8.96% (db). Biomass of freshly harvested dhaincha (*Sesbania aculeata*) crop was taken for the study. To provide a nearly homogeneous substrate for decomposition, only stems of 50 days old crop were taken as samples. Stalks were cut into equal length of 8 cm and sample of 200 g (W_1) was filled in the nylon bag (Fig 1). The sealed nylon bags were placed horizontally at five depth ranges *i.e.* 0-70 (D1), 70-140 (D2), 140-210 (D3), 210-280 (D4) and 280-350 (D5) mm. Three replications for each depth range were taken. No watering was given to biomass during decomposition period. The bags were retrieved 10, 20, 30, 40, 50, 60 and 90 days after incorporation (DAI). Soil around the bags was removed gently by hand hoe. Stalk residues were taken from the bag and placed on a 1 mm sieve to remove loose soil adhered to stalks by gentle brushing. Cleaned stalks were dried under shade and were weighed (W_2). Difference between weight of biomass before and after placement was measured to determine percent decomposition.

$$\text{Decomposition, \%} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W_1 and W_2 are weight of biomass before placement and after removal, respectively.



Fig 1: Nylon bags filled with biomass.



Fig 2: A stationary view of biomass incorporator.

Decomposition rate was found for each depth and suitable depth, where maximum decomposition takes place, was determined.

Description about biomass incorporator

Biomass incorporator is a tractor (37 kW and above) mounted innovative two-bottom machine (Fig 2). It is a combined tillage machine as it performs more than one tillage operations in a single run thereby amalgamating the advantages of active and passive machines and resulting in reduced number of trips in the field in comparison to pre-adapted tillage practices and better tractor power utilization. The machine is comprised of a cutting unit, truncated mould board and vertical rotating clod-crusher. The cutting unit cuts the crop mass in small pieces. The share of mould board plough cuts the soil slice, the truncated mould board lifts it and finally the vertical rotating clod crusher, fitted behind each bottom, pulverizes the furrow slice thereby producing desired soil fragmentation and covering the plant biomass and other remnants with the soil (Verma *et al*., 2019).

Field operation of biomass incorporator

In order to study the soil pulverization, crop mixing with soil and surface profile index with biomass incorporator; study was conducted at Research Farm of Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana (30° 54′ 38″ N latitude and 75° 48′ 45″ E longitude). Field experiments were conducted during year 2017 and 2018 on two type of soils *i.e.* loamy sand (S1) and loam (S2). These soil types broadly represent the soil type available in Punjab state (India). The mechanical analysis for finding constituents of field soil was conducted. The soil type S1 was having constituents as 745.9 $g.kg^{-1}$ sand, 122.1 $g.kg^{-1}$ silt and 132.0 $g.kg^{-1}$ clay. The soil type S2 was having constituents as 385.6 $g.kg^{-1}$ sand, 354.4 $g.kg^{-1}$ silt and 260.0 $g.kg^{-1}$ clay. Dhaincha (*Sesbania aculeata*) was taken as green manure crop. Each soil type field was divided in two subfields for two crop growth stages (H1, H2). Each field was divided into 54 equal plots of 20×3.5 m dimension wherein the performance of biomass incorporator was studied. There were three forward speed levels (F1, F2, F3) and three levels of speed of clod crusher *i.e.* rotor speed levels (R1, R2, R3) which were replicated three times. The allocation of the treatments to the various plots was done with suitable random number generation technique. The cutting unit of the machine was operated at steady rotational speed of 925 rpm. The initial dry bulk density of soil type S1 at crop growth stage I and II was 1.313 and 1.302 $g.cm^{-3}$, respectively whereas initial dry bulk density of soil type S2 at crop growth stage I and II was 1.337 and 1.350 $g.cm^{-3}$, respectively. The levels of various independent parameters under study are given in Table 1.

Depth of placement

The depth of operation or cut of the machine represents the soil working depth of the machine. It was taken as the vertical distance between the furrow ground and un-ploughed soil surface. The depth of placement (Fig 3) was measured as the distance between centre line of buried plant material and parallel soil surface line above it. The depth of cut and placement were measured at 10 places and its average was taken.

Pulverization index

The mean mass diameter (MMD) of the soil aggregate is considered as index of soil pulverization. Pulverization index was measured by determining the mean mass diameter (MMD) of soil clod by using sieve analysis method (Mehta *et al*., 2005). A set of 18 sieves having standard mesh sizes (75-0.425 mm and a pan) was taken to carry out the sieve analysis to assess the degree of pulverization.

Mixing index

The measure of the extent of mixing of the crop-mass in the soil is called as mixing index. It is the percentage of crop-mass incorporated in the soil. A square metal frame of 1 m side (inside dimension) was used to measure the crop intensity in terms of weight. Before the machine operation, the crop standing inside the square meter area was cut from the bottom and weighed. Biomass incorporator was operated in the standing crop to incorporate it in to the soil. After machine operation, square meter was placed randomly on



Fig 3: Buried biomass after operation of the machine.

Table 1: Level of various independent parameters under study.

Independent parameters	Levels	Values
Soil type (S)	2	Loamy sand (S1) Loam (S2)
Plant height (H), mm	2	685.5 (H1) obtained 36 DAS*1274.0 (H2) obtained 50 DAS
Forward speed (F), $km.h^{-1}$	3	2.10 (F1) 2.80 (F2) 3.40 (F3)
Rotor speed (R), rpm	3	300 (R1) 360 (R2) 430 (R3)

*DAS: Days after sowing.

the operated field and the pieces of the crop which were exposed 1/3rd of their length or more were collected and weighed. The mixing index in percentage was calculated as follow:

$$\text{Mixing index (MI), \%} = \frac{W_t - W_e}{W_t} \times 100$$

Where,

W_t = Total weight of crop before operation in 1 m^2 area.

W_e = Weight of exposed pieces of crop mass in 1 m^2 area after machine operation.

Surface profile coefficient

The degree of soil profile should be determined by magnitude, form and spacing of irregularities on the surface of soil after tillage and no single figure or dimensional value will represent precisely the roughness. In the present study, a low-cost method was formulated and measurement was taken to give some approximate value to the surface profile after the operation of biomass incorporator. Conventional two-bottom mould board plough was taken as control. It was assumed that the field was leveled before the machine operation and effect of slope was neglected. The basic method prescribed by Rizvi (1991) was used for calculating the soil surface profile coefficient. For this a 1×1 m iron frame was fabricated. At each corner, at midpoint of each side and at the centre of the frame; total nine pegs of height 30 cm were fixed. Graduation from bottom on each peg indicated the depth of freshly tilled soil at each place. In operation, the frame was dropped on the ground in the random manner immediately after the machine operation

Table 2: Biomass decomposition at different depths of placement and different DAI.

Days after incorporation	Depth of placement of biomass	Weight, g		Decomposed biomass		Remarks
		Initial	Final	g	%	
10	D1	200.0	174.0	26.0	13.00	Stingy smell, significant living organisms were visible through naked eye.
	D2	200.0	137.0	63.0	31.50	
	D3	200.0	141.5	58.5	29.25	
	D4	200.0	151.5	48.5	24.25	
	D5	200.0	155.9	44.1	22.05	
20	D1	200.0	152.0	48.0	24.00	Relatively less smell than 10 DAI.
	D2	200.0	118.0	82.0	41.00	
	D3	200.0	127.5	72.5	36.25	
	D4	200.0	132.4	67.6	33.80	
	D5	200.0	139.1	60.9	30.45	
30	D1	200.0	125.8	74.2	37.10	Key substrate vanished from the stems. One could see through the stem.
	D2	200.0	104.8	95.2	47.60	
	D3	200.0	111.9	88.1	44.05	
	D4	200.0	117.3	82.7	41.35	
	D5	200.0	126.4	73.6	36.80	
40	D1	200.0	114.0	86.0	43.00	Biomass reduced to about 50%. No smell was noticed.
	D2	200.0	90.0	110.0	55.00	
	D3	200.0	100.1	99.9	49.95	
	D4	200.0	109.0	91.0	45.50	
	D5	200.0	115.1	84.9	42.45	
50	D1	200.0	98.8	101.2	50.60	Biomass became very soft to tear apart
	D2	200.0	70.4	129.6	64.80	
	D3	200.0	84.5	115.5	57.75	
	D4	200.0	100.8	99.2	49.60	
	D5	200.0	107.7	92.3	46.15	
60	D1	200.0	68.0	132.0	66.00	Significant change in colour of all samples. Only outer cover of sample was left which was very soft.
	D2	200.0	39.0	161.0	80.50	
	D3	200.0	53.2	146.8	73.40	
	D4	200.0	68.0	132.0	66.00	
	D5	200.0	70.8	129.2	64.60	
90	D1	200.0	54.6	145.4	72.70	Very light weight and fragile left over of the samples. A minute force was required to convert it into small particles.
	D2	200.0	26.9	173.1	86.55	
	D3	200.0	36.5	163.5	81.75	
	D4	200.0	52.7	147.3	73.65	
	D5	200.0	56.6	143.4	71.70	

D1: 0-70 mm, D2: 70-140 mm, D3: 140-210 mm, D4: 210-280 mm, D5: 280-350 mm.

and depth of ploughed soil surface at each of the nine-peg location was recorded. The surface profile coefficient data were determined by calculating the standard deviation of the recorded values. This method was replicated thrice and the average value was taken. The field having smaller average value indicates smoother surface following the tillage and the larger values indicate rougher surface profile.

RESULTS AND DISCUSSION

Suitable depth of biomass placement for maximum decomposition

Five levels of depth of biomass placement were taken and its effect on biomass decomposition was studied 10, 20, 30, 40, 50, 60 and 90 days after incorporation (DAI). The view of decomposed biomass placed at different depths and after different decomposition period is given in Fig 4. The biomass decomposition data along with visual observations at various depths of placement, after different days of incorporation, is presented in Table 2 and has been graphically shown in Fig 5.

Results showed that samples of *dhaincha* crop decomposed by 13.0, 31.5, 29.25, 24.25 and 22.05% at depth range D1, D2, D3, D4 and D5, respectively 10 days after incorporation. At this stage, biomass placed at different depth levels produced stingy smell on retrieval. The decomposition rate trends were similar amongst different depths. After 30 days of incorporation, the key substrate vanished from the stems and it was possible to clearly see through the hollow stem. At stage 40 DAI, it was recorded that weight of original biomass reduced by about 50%

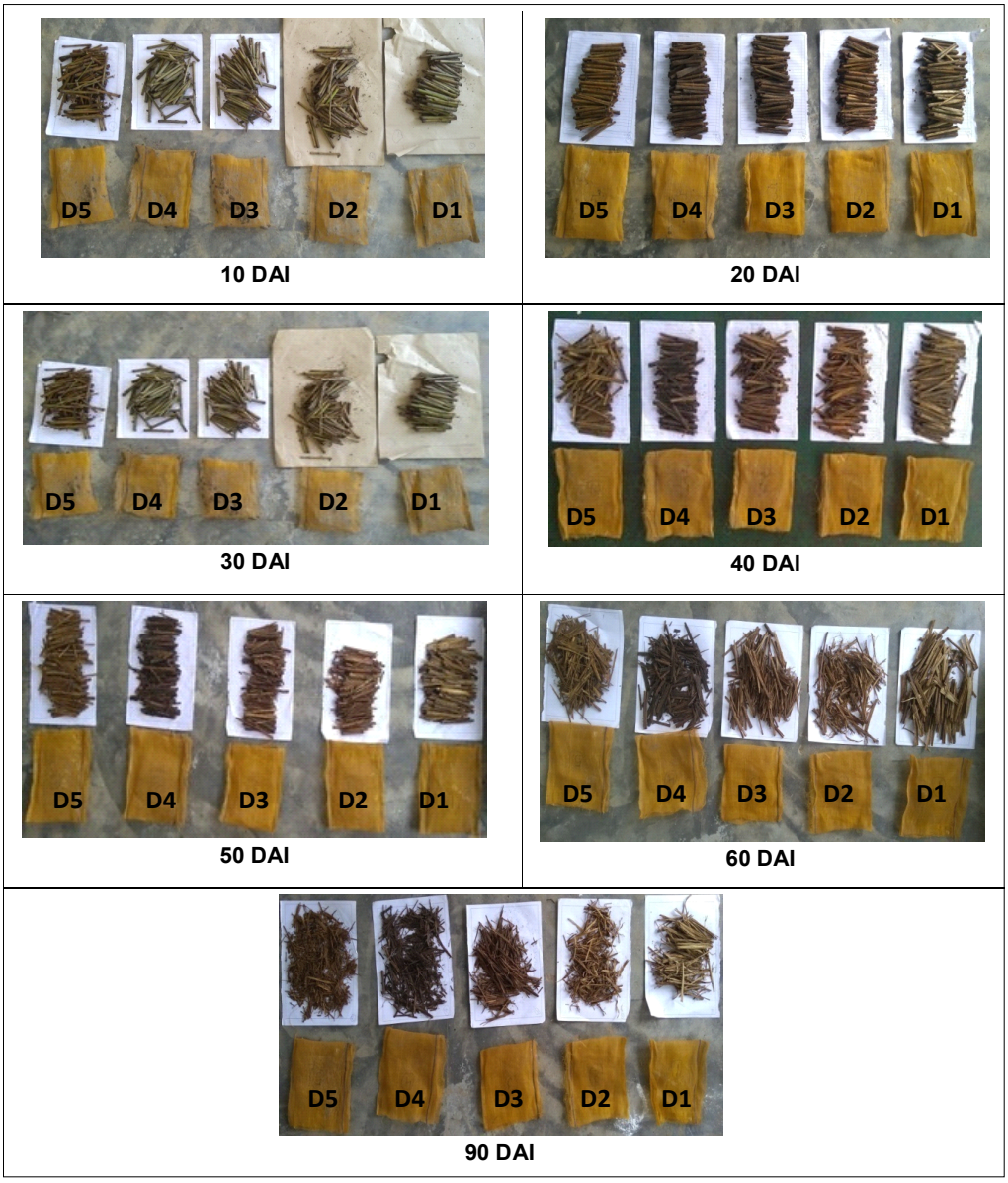

Fig 4: Decomposed biomass placed at different depths and different DAI.

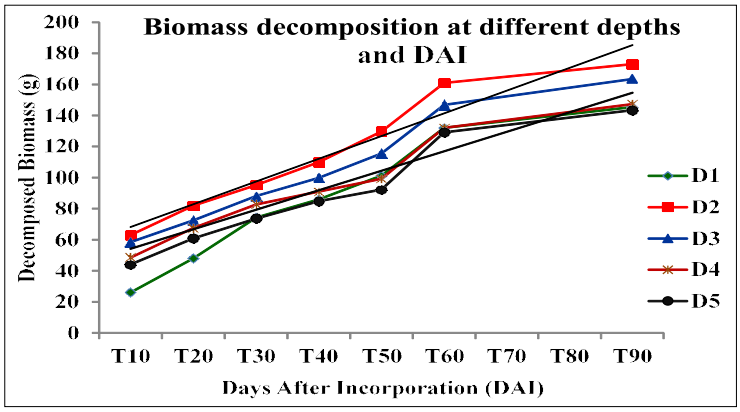

Fig 5: Biomass decomposition at different depths and different DAI.

Table 3: Effect of soil type (S), plant height (H), forward speed (F) and rotor speed (R) on pulverization index (mm).

S			S1		S2		Mean for H × F × R		Mean for F × R	Mean for H × F		Mean for F	Mean for R
H			H1	H2	H1	H2	H1	H2		H1	H2		
		R1	6.10	5.60	26.05	25.10	16.08^{de}	15.35^{fe}	15.71^{dc}				17.94^{a}
	F1	R2	5.87	5.37	25.80	24.65	15.84^{de}	15.01^{feg}	15.42^{de}	15.33^{d}	14.67^{e}	15.00^{c}	16.94^{b}
Mean for		R3	4.10	3.58	24.05	23.70	14.08^{fhg}	13.64^{h}	13.86^{f}				15.05^{c}
S × H × F × R		R1	8.02	7.94	28.40	27.35	18.21^{bc}	17.65^{c}	17.93^{b}				
	F2	R2	6.25	5.75	26.20	25.60	16.23^{de}	15.68^{de}	15.95^{cd}	16.75^{c}	15.73^{d}	16.24^{b}	
		R3	5.90	5.50	25.75	22.26	15.83^{de}	13.88^{hg}	14.85^{e}				
		R1	10.40	10.09	30.65	29.60	20.53^{a}	19.85a	20.19^{a}				
	F3	R2	9.03	9.70	30.10	28.90	19.57^{a}	19.30^{ab}	19.43^{a}	19.02^{a}	18.36^{b}	18.69^{a}	
		R3	7.02	6.42	26.90	25.42	16.96^{dc}	15.92^{de}	16.44^{c}				
		F1	5.36^{g}	4.85^{g}	25.30^{d}	24.48^{d}			Mean for				
Mean for S × H × F		F2	6.72^{f}	6.40^{f}	26.78^{c}	25.07^{d}			plant height	17.03^{a}	16.25^{b}		
		F3	8.82^{e}	8.74^{e}	29.22^{a}	27.97^{b}			(H)				
		R1	8.17^{e}	7.88^{fe}	28.37^{a}	27.35^{b}				18.27^{a}	17.61^{b}		
Mean for S × H × R		R2	7.05^{f}	6.94^{f}	27.37^{ab}	26.38^{bc}			Mean for	17.21^{bc}	16.66^{c}		
		R3	5.67^{g}	5.17^{g}	25.57^{c}	23.79^{d}			H × R	15.62^{d}	14.48^{e}		
		R1	5.85^{h}		25.58^{c}								
	F1	R2	5.62^{h}		25.23^{cd}								
		R3	3.84^{i}		23.88^{e}								
		R1	7.98^{g}		27.88^{b}								
Mean for S × F × R	F2	R2	6.00^{h}		25.90^{c}								
		R3	5.70^{h}		24.01^{de}								
		R1	10.25^{f}		30.13^{a}								
	F3	R2	9.37^{f}		29.50^{a}								
		R3	6.72^{gh}		26.16^{c}								
Mean for S × H			6.97^{c}	6.66^{c}	27.10^{a}	25.84^{b}							
Mean for S × F		F1	5.10^{f}		24.89^{c}								
		F2	6.56^{e}		25.93^{b}								
		F3	8.78^{d}		28.60^{a}								
Mean for S × R		R1	8.03^{d}		27.86^{a}								
		R2	7.00^{e}		26.88^{b}								
		R3	5.42^{f}		24.68^{c}								
Mean for soil type (S)			6.81^{b}		26.47^{a}								

Note: Within a sub table, mean values with the same letter are not significantly different (p>0.05).

particularly at depth D2 and D3. At stage 50 DAI, the biomass became very soft to tear apart. At stage 60 DAI, significant change in colour of all the samples was noticed. At this stage, only thin outer layer of sample was left which was very soft and was easy to shred apart. Results indicated that the decomposition of biomass varied significantly with the depth of placement. The higher decomposition of biomass at depth D2 was mainly because of warm and moist zone. Decomposition was low in top most layer, may be because of drying up of top soil layer. Rapid loss of soil moisture in upper zone may have adversely affected the microbial activity. However, increase in placement beyond 210 mm did not show positive relation between placement and decomposition. This was probably due to poor exchange of gases and prevailing soil conditions.

In all, the results indicated that among the various depth levels under study, placement depth of 70-140 mm was best suited for maximum decomposition rate. Stockfisch *et al.* (1999) also reported that leaving the plant material to the uppermost soil layer, lowered the local accessibility of biomass to soil microorganisms. Results were also in line with Virappa (2010), who determined effect of depth of placement on biomass decomposition in the field condition, after 10, 25 and 40 days of incorporation in typical alfisol (red soil) region and vertisol region (black soil).

Depth of placement

The depth of operation of biomass incorporator ranged between 167-181 mm with the average of 174.7 mm. This depth level was easily maintained in most of the runs.

Table 4: Effect of soil type (S), plant height (H), forward speed (F) and rotor speed (R) on mixing index (%).

S			S1		S2		Mean for H × F × R		Mean for F × R	Mean for H × F		Mean for F	Mean for R
H			H1	H2	H1	H2	H1	H2		H1	H2		
		R1	95.19	96.22	94.94	95.64	95.07^{h}	95.93^{efg}	95.50^{d}				94.97^{b}
	F1	R2	97.91	98.00	97.73	97.52	97.82^{ab}	97.76^{ab}	97.79^{a}	96.95^{ab}	97.17^{a}	97.06^{a}	97.12^{a}
		R3	98.05	98.04	97.86	97.59	97.96^{a}	97.82^{ab}	97.89^{a}				97.23^{a}
		R1	94.28	95.70	94.14	95.57	94.21^{i}	95.64^{fgh}	94.92^{e}				
Mean for S × H × F × R	F2	R2	97.08	97.38	96.47	96.69	96.78^{dc}	97.04^{bcd}	96.91^{bc}	96.03^{d}	96.66^{bc}	96.34^{b}	
		R3	97.14	97.47	97.07	97.14	97.11^{bcd}	97.31^{abc}	97.21^{b}				
		R1	93.69	95.59	93.62	95.09	93.66^{i}	95.34^{gh}	94.50^{e}				
	F3	R2	97.10	97.07	95.97	96.53	96.54^{cde}	96.80^{dc}	96.67^{c}	95.50^{e}	96.34^{cd}	95.92^{c}	
		R3	96.53	97.11	96.10	96.62	96.32^{def}	96.87^{dc}	96.59^{c}				
		F1	97.05^{ab}	97.42^{a}	96.84^{ab}	96.92^{ab}			Mean for				
Mean for S × H × F		F2	96.17^{cde}	96.85^{ab}	95.89^{de}	96.47^{bcd}			plant height	96.16^{b}	96.72^{a}		
		F3	95.77^{ef}	96.59^{bc}	95.23^{f}	96.08^{cde}			(H)				
		R1	94.39^{e}	95.84^{d}	94.23^{e}	95.43^{d}				94.31^{c}	95.64^{b}		
Mean for S × H × R		R2	97.36^{ab}	97.48^{ab}	96.72^{c}	96.91^{bc}			Mean for	97.04^{a}	97.20^{a}		
		R3	97.24^{abc}	97.54^{a}	97.01^{abc}	97.12^{abc}			H × R	97.13^{a}	97.33^{a}		
		R1	95.71^{hi}		95.29^{ij}								
	F1	R2	97.96^{ab}		97.63^{abcd}								
		R3	98.05^{a}		97.73^{abc}								
		R1	94.99^{ijk}		94.86^{jk}								
Mean for S × F × R	F2	R2	97.23^{bcde}		96.58^{efg}								
		R3	97.31^{abcde}		97.11^{cdef}								
		R1	94.64^{jk}		94.36^{k}								
	F3	R2	97.09^{cdef}		96.25^{gh}								
		R3	96.82^{defg}		96.36^{fgh}								
Mean for S × H			96.33^{b}	96.95^{a}	95.99^{c}	96.49^{b}							
Mean for S × F		F1	97.24^{a}		96.88^{ab}								
		F2	96.51^{bc}		96.18^{c}								
		F3	96.18^{c}		95.66^{d}								
Mean for S × R		R1	95.11^{c}		94.83^{c}								
		R2	97.42^{a}		96.82^{b}								
		R3	97.39^{a}		97.06^{ab}								
Mean for soil type (S)			96.64^{a}		96.24^{a}								

Note: Within a sub table, mean values with the same letter are not significantly different (p>0.05).

A depth adjustment wheel was provided in the machine and machine worked well while maintaining depth of operation in both type of soils and at different stages of crop growth. No need of further increasing the depth of operation was felt as the quantity of soil mass excavated up to this depth was sufficient to cover the crop mass completely. Moreover, further increase in depth of operation would result in higher cost of operation as energy consumption would increase. The average depth of placement of biomass ranged from 92-131 mm.

Pulverization index, mixing index and surface profile coefficient

The mean pulverization index at different stages of the crop growth in different soil types, at different levels of forward speed and rotor speed is given in Table 3. The mean pulverization index varied from 3.58 to 30.65 mm among all the treatments. The maximum value of pulverization index was observed for treatment S2H1F3R1 while minimum value was recorded for treatment S1H2F1R3. The mean mixing index with biomass incorporator at different stages of the crop growth in different soil types, at different levels of forward speed and rotor speed is given in Table 4. Mean mixing index varied from 93.62% (S2H1F3R1) to 98.05% (S1H1F1R3) among all the treatments.

The surface profile coefficient recorded at different treatments has been presented in Table 5 and shown in Fig 6. The value of surface profile coefficient ranged between 24.2 and 50.6 mm. The minimum value of surface profile coefficient was observed for treatment S1H1F2R2 whereas maximum value was recorded for treatment S2H2F1R1. In particular soil type, the surface profile coefficient was higher at crop growth stage II than at crop growth stage I. This may be because of higher density of biomass at crop growth stage II. Further, it was observed that surface profile coefficient depend on the skill of the operator also and it may increase if the tractor operator is not skillful. No clogging or entanglement of plant material on the machine was recorded during its operation at different levels of soil type, plant height, forward speed and rotor speed.

Table 5: Surface profile coefficient at different treatment levels.

Soil type	Plant height	Forward speed	Rotor speed	Surface profile coefficient (mm)
S1	H1	F1	R1	37.0
			R2	33.3
			R3	33.4
		F2	R1	36.7
			R2	24.2
			R3	34.6
		F3	R1	37.3
			R2	33.2
			R3	33.4
	H2	F1	R1	47.0
			R2	43.1
			R3	42.9
		F2	R1	45.7
			R2	43.1
			R3	43.2
		F3	R1	47.0
			R2	43.4
			R3	43.0
S2	H1	F1	R1	43.8
			R2	38.5
			R3	42.9
		F2	R1	40.1
			R2	38.4
			R3	38.0
		F3	R1	43.4
			R2	38.3
			R3	38.5
	H2	F1	R1	50.6
			R2	47.4
			R3	41.7
		F2	R1	48.5
			R2	44.2
			R3	41.4
		F3	R1	47.5
			R2	42.9
			R3	41.1

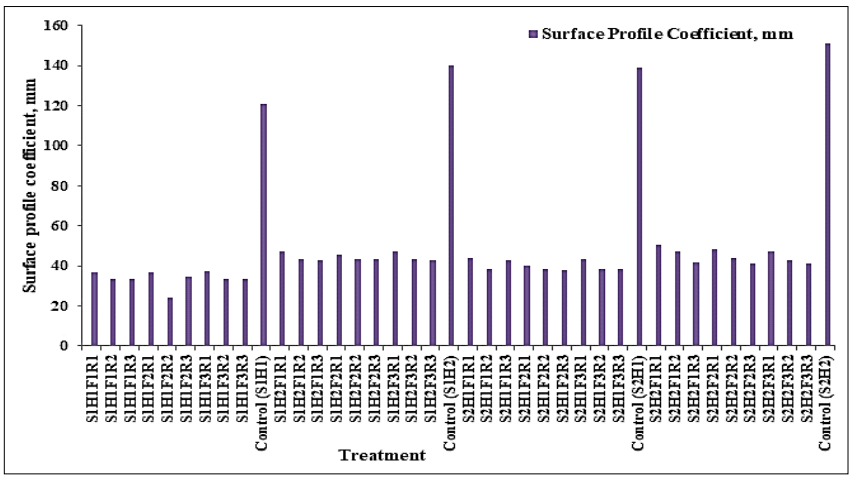

Fig 6: Surface profile coefficient at different operational parameters.

CONCLUSION

1. From the interaction of soil and biomass at various depths, it was found that depth range of 70-140 mm was most appropriate zone for incorporation in view of obtaining higher decomposition rate. Stems of 50 days old *dhaincha* crop decomposed by 13.0, 31.5, 29.25, 24.25 and 22.05% at depth range 0-70 (D1), 70-140 (D2), 140-210 (D3), 210-280 (D4) and 280-350 (D5) cm, respectively 10 days after incorporation. About 55% of biomass, incorporated at depth range D2, got decomposed 40 DAI.
2. The average depth of operation of biomass incorporator was 174.7 mm whereas average depth of placement of biomass ranged from 92-131 mm.
3. The soil pulverization index with the machine at different levels of soil type, plant height, forward speed and rotor speed varied from 3.58 to 30.65 mm. Mean mixing index varied from 93.62 to 98.05% among all the treatments
4. The surface profile coefficient with the machine ranged between 24.2 and 50.6 mm.
5. Efficient mixing of the biomass into the soil with thorough cover of pulverized soil was achieved with rational field undulation.

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