Biomass, Biochemical Composition and Decomposition Behavior of Roots and Shoots of Major Rainfed Crops

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ABSTRACT: A Study was conducted during 2012-14 to quantify root and shoot biomass of 2 cultivars each of 8 rainfed crops (sorghum, greengram, sunflower, maize, castor, pigeonpea, cowpea and horsegram), to determine their biochemical composition and to examine their decomposition behavior in soil. Root biomass of all the crops and cultivars was lower than the respective shoot biomass. Roots accounted for 12.07% (Horsegram, CRHG 4) to 35.26% (Maize, DHM 117) of the total plant biomass. Root biomass (averaged over cultivars) varied widely with crops, ranging from as low as 5.24 g/plant (Horsegram) to as high as 158.23 g/plant (Pigeonpea) and was in the order pigeonpea > sorghum > maize > castor > sunflower > cowpea > greengram > horsegram. Shoot:root ratios ranged from 1.84 (Maize, DHM 117) to 7.29 (Horsegram, CRHG 4). There were marked differences in shoot:root ratios among crops and even cultivars within crops. Biochemical analysis revealed that cell wall was the dominant fraction of the plant tissue accounting for up to 3/4th of the tissue. Regardless of crop or cultivar, roots had lower soluble cell contents and higher cell wall contents than shoots. Averaged across crops and cultivars, lignin content of roots was 13.76% as against 8.38% for shoots. Crops differed significantly in the lignin content of their roots, which ranged from 8.25% in maize to 19.15% in pigeonpea. The dicots with taproot systems (castor, sunflower, greengram, cowpea, horsegram, pigeonpea) had higher lignin content than the monocots with fibrous root systems (maize, sorghum). Lignin/N ratios of roots were 2-3 times higher than those of shoots. Patterns of carbon mineralization of roots and shoots were exponential in nature, being faster in the initial stages and slowing down over time. Regardless of crops and cultivars, roots exhibited distinctly slower carbon mineralization than corresponding shoots. Averaged across crops and cultivars, per cent C mineralized in 120 days was 37.35% in roots as against 50.22% in shoots. Lignin content (r = -0.684**) and lignin/N ratio (r = -0.636**) had a highly significant negative relationship with % C mineralized.

Key words: Biomass, biochemical composition, carbon mineralization, lignin, root, shoot

Introduction

The root system constitutes a major part of the plant body in terms of both function and bulk. Plant roots have received much less attention than above ground plant parts because they are hidden from view below ground and are intricately interspersed throughout the heterogeneous soil mass, which makes them extremely difficult to extract or to study *in situ*. Vital functions that are essential for growth and development of plants performed by roots include anchorage and support, absorption and conduction of water, oxygen and nutrients from the soil, storage of water and carbohydrates, synthesis of plant growth hormones and sensing and signaling of plant water stress. At the ecosystem level, roots play a crucial role in the storage and turnover of carbon in the terrestrial ecosystem. Roots are the primary vector for most carbon entering the soil carbon pool. It is very likely that most of the organic carbon in soil is derived from roots (Rasse *et al*., 2005).

In many arable systems, especially those in subtropical and tropical regions, since above ground plant residues are grazed or removed, root-derived C is the primary C input to soil and contributor to soil organic carbon (Heal *et al*., 1997). In agroecosystems in which no above ground crop residues or external sources of organic matter are added, roots are the only source of organic carbon in soil. Since roots play such a significant role in soil organic matter formation and storage, strategies for removing carbon from the atmosphere and sequestering it in soil must essentially consider, or even centre around roots.

Roots and above ground plant parts (residues) recycled into the soil being the primary sources of organic carbon in soil, a comparison of their relative contribution to soil organic matter is inevitable. Many studies (Campbell *et al*., 1991; Molina *et al*., 2001; Reicosky *et al*., 2002) indicate that the relative contribution of plant roots to soil organic C stocks is larger than that of plant shoots. Johnson *et al*. (2006) proposed that 1.5-3 times more root C than shoot C is stabilized in the SOC pool, which suggests that root biomass makes a greater contribution to soil C sequestration than above ground residues. Root biomass has considerable value for SOC storage because of the amount of C contained in these residues and the fact that they are less easily mineralized and are thus more likely to become chemically or physically stabilized in deeper soil layers (Bolinder *et al*., 1999).

Since root contribution to stable SOC is significant, strategies for increasing soil organic matter and transferring atmospheric

C to soil must essentially consider the crucial role the roots play. In agroecosystems, some idea of how much carbon can be sequestered in soil under different cropping systems can be obtained by quantifying root biomass of crops, determining the biochemical composition of the roots and studying their decomposition patterns. This study aimed to quantify the root biomass of important rainfed crops and crop cultivars, determine the biochemical composition of the roots and shoots and investigate their decomposition behavior.

Materials and Methods

Determination of shoot and root biomass

Two cultivars each of eight rainfed crops were grown at Hayathnagar Research Farm of ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA) over a 3 year period (*kharif* seasons of 2012, 2013 and 2014) in plastic containers under open field conditions. The details of the crops and cultivars are given in Table 1.

Table 1 : Details of crops and cultivars

Year	Crop	Cultivar	Description
2012	Sorghum [*Sorghum bicolor* (L.) *Mench*]	SPV 462	Variety
		CSH 16	Hybrid
	Greengram [*Vigna radiata* (L.) R. Wilczek]	ML 267	Old variety
		LGG 460	New variety
	Sunflower (*Helianthus annuus* L.)	Morden	Variety
		KBSH 44	Hybrid
2013	Maize (*Zea mays* L.)	Varun	Variety
		DHM 117	Hybrid
	Pigeonpea [*Cajanus cajan* (L.) Millsp.]	PRG 158	Variety
		ICPH 2740	Hybrid
	Castor *(Ricinus communis* L.)	Kranthi	Variety
		PCH 111	Hybrid
2014	Cowpea [*Vigna unguiculata* (L.) Walp.]	C 152	Old variety
		APFC 10-1	New variety
	Horsegram [*Macrotyloma unifloru* (Lam.) Verdc.]	CRHG 4	Mutant derivative of Hyderabad local
		CRIDA 18R	Mutant derivative of K 42

Plants were grown in 64 cm tall 100 L plastic containers filled up to 60 cm depth with 120 kg soil. To allow free drainage, 7 holes were drilled in the bottom of the container. A single plant was grown in each container. Plants were grown in the open, in conditions identical to rainfed, and were irrigated only when they exhibited signs of water stress. Fertilizers (N, P, K) were applied through DAP, urea and muriate of potash as per recommended doses for the crops and equally to varieties within crops. Each cultivar of each crop was grown in triplicate. The biomass of plants grown in large containers is not representative of field grown plants, but the root shoot ratios of container grown plants are similar to field grown plants (Srinivas *et al*., 2017) and root biomass of field grown plants can be estimated from shoot biomass using the shoot:root ratios. Root systems of the plants were extracted at late flowering stage (68, 49, 66, 65, 104, 72, 54 and 52 days after sowing of sorghum, greengram, sunflower, maize, pigeonpea, castor, cowpea and horsegram respectively) which is generally the stage at which root biomass reaches a peak, by washing away the soil in the containers with a jet of water on a wire mesh with 2 mm openings. Fragments of roots separated from the root system during washing and collected on the wire mesh were recovered and added to the root portion. Root and shoot portions were dried at 65 ºC in a hot air oven and weights were recorded.

Determination of biochemical composition

For determining biochemical composition, plant parts were ground to pass 1 mm sieve and tissue fractions were determined using the detergent fibre fractionation procedure (Goering and Van Soest, 1970) as described by Dutta (1999). Carbon and nitrogen in the samples were determined by solid sample dry combustion method (AOAC, 2006). C/N ratio and Lignin/N ratio as indicators of decomposability were calculated.

Laboratory decomposition study

For studying decomposition behavior, ground 1 mm sieved biomass of roots and shoots were mixed into soil @ 5 g plant material per 500 g of soil and incubated at water content equivalent to field capacity in sealed plastic jars along with alkali solution for trapping CO_2 released upon decomposition. Jars were opened at 4, 10, 18, 28, 38, 48, 58, 68, 78, 88, 98, 108 and 120 days after start of incubation and trapped CO_2 was determined by precipitating carbonate with barium and titrating the remaining alkali with acid (Singh *et al*., 1999). Per cent of added C mineralized at the end of 120 days of incubation was calculated as

$$\frac{\text{cumulative C mineralized in treated} - \text{cumulative C mineralized in control}}{\text{C added}} \times 100$$

Simple correlations were worked out between % C mineralized and relevant residue quality parameters.

Presentation of data

Data presented in the results section are means of three plants. No statistical analysis was performed as this is more of a characterization study. Pearson's coefficients of correlation between % C mineralized in 120 days and relevant residue

quality parameters were determined and their significance was tested at p = 0.05 and p = 0.01.

Results and Discussion

Biomass and shoot: root ratios

Root and shoot biomass were determined by destructive sampling at late flowering stage. The late flowering stage was selected for sampling because annual crops generally attain maximum root biomass at this stage (Gregory, 2006). The biomass of roots for all the crops and cultivars was much lower than the respective shoot biomass (Table 2). Roots accounted for 12.07% (Horsegram, CRHG 4) to 35.26% (Maize, DHM 117) of total biomass. Root biomass and root contribution to total plant biomass are likely to be higher as the measurement of root biomass based on root extraction from soil by washing leads to underestimation of the root biomass as considerable root material is lost during washing and subsequent handling (Judd *et al*., 2015). Root biomass (averaged over cultivars) varied widely with crops, ranging from as low as 5.24 g/plant (Horsegram) to as high as 158.23 g/plant (Pigeonpea) and was in the order pigeonpea > sorghum > maize > castor > sunflower > cowpea > greengram > horsegram. Crop species are known to vary widely in root biomass (Welbank *et al.*, 1974; Gregory *et al.*, 1978; Paustian *et al*., 1990; Iwama and Yamaguchi, 1996). Varietal differences with respect to root biomass were more conspicuous in sorghum and maize. Significant differences in root biomass of cultivars within crop species have been reported for rice (Hassan *et al.* 2016) and wheat (Bustos *et al*., 2018).

Table 2 : Root and shoot biomass (g/plant) and shoot:root ratios of crops and cultivars

Crop	Cultivar	Root biomass (g/plant)	Shoot biomass (g/plant)	Total biomass (g/plant)	Root biomass as % of total biomass	Shoot:Root ratio
	SPV 462	152.75	488.49	641.24	23.82	3.20
Sorghum	CSH 16	105.86	311.96	417.82	25.34	2.95
	Mean	**129.31**	**400.23**	**529.53**	**24.58**	**3.08**
	ML 267	13.47	81.63	95.10	14.16	6.06
Greengram	LGG 460	10.85	69.22	80.07	13.55	6.38
	Mean	**12.16**	**75.43**	**87.59**	**13.86**	**6.22**
	Morden	32.45	157.27	189.72	17.10	4.85
Sunflower	KBSH 44	45.99	259.26	305.25	15.07	5.64
	Mean	**39.22**	**208.27**	**247.49**	**16.09**	**5.25**
	Varun	41.33	102.96	144.29	28.64	2.49
Maize	DHM 117	100.66	184.84	285.50	35.26	1.84
	Mean	**71.00**	**143.90**	**214.90**	**31.95**	**2.17**
	Kranthi	35.48	206.27	241.75	14.68	5.81
Castor	PCH 111	49.10	256.55	305.65	16.06	5.23
	Mean	**42.29**	**231.41**	**273.70**	**15.37**	**5.52**
	PRG 158	160.83	819.87	980.70	16.40	5.09
Pigeonpea	ICPH 2740	155.63	724.96	880.59	17.67	4.68
	Mean	**158.23**	**772.42**	**930.65**	**17.04**	**4.89**
	C 152	16.52	95.39	111.91	14.76	5.77
Cowpea	APFC 10-1	18.96	99.62	118.58	15.99	5.25
	Mean	**17.74**	**97.51**	**115.25**	**15.38**	**5.51**
	CRHG 4	4.85	35.34	40.19	12.07	7.29
Horsegram	CRIDA 18R	5.63	39.85	45.48	12.38	7.08
	Mean	**5.24**	**37.60**	**42.84**	**12.23**	**7.19**

Shoot:root ratios (Table 2) ranged from 1.84 (Maize, DHM 117) to 7.29 (Horsegram, CRHG 4). There were marked differences in shoot:root ratios among crops and even cultivars within crops. Shoot:root ratios of crops, averaged over cultivars, were in the order horsegram > greengram > castor > cowpea > sunflower > pigeonpea > sorghum > maize. The cereal monocots (sorghum and maize) with fibrous root systems had narrower shoot:root ratios compared to the dicots with tap root systems, indicating a higher percentage allocation of photosynthetically fixed carbon to roots in the monocots. Shoot:root ratios in this study are in general agreement with values in published literature for different crops (Welbank *et al.*, 1974; Gregory *et al.*, 1978; Paustian *et al.*, 1990; Johnson *et al.,* 2006).

Biochemical composition

Plant cells have two major components, cell contents and cell walls. The cell content fraction contains most of the organic acids, soluble carbohydrates, proteins, fats and soluble ash. The cell wall fraction includes hemicellulose, cellulose, lignin and insoluble ash. In most crop residues, the cell wall fraction accounts for 60-80% of dry matter (Xiong, 1986). Cell walls of crop residues consist mainly of hemicellulose, cellulose and lignin. Lignin represents between 5-20% of crop residue dry matter (Meng, 2002). Lignin is a complex and high molecular weight polymer with three-dimensional networks of phenylpropane units. Lignin occurs between the cells and cell walls and is physically and chemically associated with cell wall polysaccharides and imparts strength and rigidity to the plant.

The process of microbial breakdown of plant residues in soil is identical to the degradation of plant material in the rumen of livestock. Most of the methods for fractionation of residues have in fact been developed for animal feeds and fibres. Biodegradability of plant litter material is often characterized through biochemical fractionation, such as the method of Goering and Van Soest (1970). This method leads to the quantification of a series of organic molecule fractions displaying decreasing biodegradability, lignin being the most resistant fraction.

Biochemical analysis of root and shoot samples in the present study revealed (Table 3) that cell wall was the dominant fraction of the plant tissue, except in a few cases of shoot material where the soluble cell contents slightly exceeded the cell wall contents. In majority of the cases, especially in roots, cell wall contents accounted for 2/3rd to 3/4th of the tissue. Cellulose was the dominant cell wall constituent accounting for up to 40% of the plant material. Root samples had high ash content, as high as 19.36% in maize, DHM 117. Much of this ash is due to mineral

Table 3 : Biochemical composition of roots and shoots of crops and cultivars

Crop	Cultivar	Plant part	Cell contents %	Hemi-cellulose %	Cellulose %	Lignin %	Ash %	C %	N %	C/N	Lignin/N
Sorghum	SPV 462	Root	28.39	15.06	33.19	8.54	14.82	32.28	0.90	35.87	9.49
		Shoot	36.04	21.03	37.27	4.91	0.76	41.29	1.32	31.28	3.72
	CSH 16	Root	30.12	13.67	31.09	9.16	15.96	32.51	1.02	32.03	9.02
		Shoot	33.47	20.80	39.10	5.76	0.88	41.23	1.37	30.20	4.22
Greengram	ML 267	Root	35.11	17.40	25.43	15.16	6.90	35.37	2.92	12.13	5.20
		Shoot	51.22	15.53	24.15	8.38	0.72	39.99	3.50	11.44	2.40
	LGG 460	Root	37.88	15.21	26.30	13.82	6.79	35.92	2.85	12.62	4.86
		Shoot	54.04	13.15	22.40	9.40	1.01	40.49	3.60	11.26	2.61
Sunflower	Morden	Root	39.14	11.87	27.35	13.28	8.37	32.15	1.32	24.45	10.10
		Shoot	50.47	14.25	24.53	9.90	0.85	38.11	2.24	17.05	4.43
	KBSH 44	Root	42.10	11.24	27.37	12.47	6.82	33.20	1.19	28.01	10.52
		Shoot	49.98	16.13	23.59	9.57	0.73	37.97	2.21	17.22	4.34
Maize	Varun	Root	22.98	19.73	32.27	7.79	17.23	33.59	1.01	33.42	7.75
		Shoot	27.21	30.84	36.41	4.62	0.92	42.22	1.45	29.22	3.20
	DHM 117	Root	22.89	16.59	32.46	8.70	19.36	34.09	1.06	32.16	8.21
		Shoot	28.34	29.47	36.88	4.26	1.06	42.16	1.55	27.28	2.75
Castor	Kranthi	Root	30.82	16.17	31.85	12.41	8.76	36.87	1.540	23.94	8.06
		Shoot	44.52	17.29	31.04	6.30	0.84	42.24	2.54	16.63	2.48
	PCH 111	Root	32.20	14.35	35.54	10.83	7.08	37.51	1.65	22.73	6.56
		Shoot	46.06	17.41	30.73	5.23	0.58	43.88	2.68	16.40	1.96
Pigeonpea	PRG 158	Root	26.77	16.64	27.66	19.44	9.50	36.98	2.40	15.44	8.12
		Shoot	34.47	18.76	30.44	15.97	0.37	48.04	3.54	13.57	4.51
	ICPH 2740	Root	27.77	13.26	32.00	18.86	8.10	35.81	2.42	14.83	7.81
		Shoot	37.14	18.32	28.01	16.07	0.46	47.90	3.66	13.09	4.39
Cowpea	C 152	Root	31.92	16.64	28.35	15.79	7.30	35.14	2.60	13.52	6.07
		Shoot	48.58	13.37	28.69	8.79	0.58	38.95	3.60	10.82	2.44
	APFC 10-1	Root	26.11	16.74	31.68	17.11	8.36	35.23	2.51	14.04	6.82
		Shoot	53.14	15.43	22.82	7.91	0.70	38.19	3.34	11.43	2.37
Horsegram	CRHG 4	Root	23.10	18.53	31.49	17.99	8.90	36.30	2.40	15.13	7.50
		Shoot	50.41	15.01	25.84	7.94	0.80	39.82	3.23	12.33	2.46
	CRIDA 18R	Root	23.54	18.32	31.22	18.80	8.13	37.08	2.49	14.89	7.55
		Shoot	49.21	17.02	24.05	9.04	0.68	40.93	3.21	12.75	2.82

soil adhering to roots. Ash contents were higher in roots of maize and sorghum - monocots with fibrous root systems. Correction for ash content due to mineral soil would result in higher values of all the other fractions, including lignin, in root samples.

Regardless of crops and cultivars, roots had lower soluble cell contents and higher cell wall contents than shoots. Lignin, the constituent most important in terms of decomposition, soil organic matter formation and long-term C sequestration, was considerably higher in roots than in shoots irrespective of crop and cultivar. Averaged across crops and cultivars (means not shown), lignin content of roots was 13.76% as against 8.38% for shoots. Higher lignin content of roots over shoots has been reported earlier by several researchers (Puget and Drinkwater, 2001; Fernandez *et al.*, 2003; Abiven *et al.*, 2005).

Crops differed significantly in the lignin content of their roots, which ranged from 8.25% in maize to 19.15% in pigeonpea (Figure 1). The dicots with taproot systems (castor, sunflower, greengram, cowpea, horsegram, pigeonpea) had higher lignin content than the monocots with fibrous root systems (maize, sorghum). Differences in lignin content among crops have important implications for carbon sequestration. Choice of crops like pigeonpea, which have deep root systems, large root biomass and high lignin content, or their inclusion in cropping systems, can lead to greater sequestration of carbon in soil.

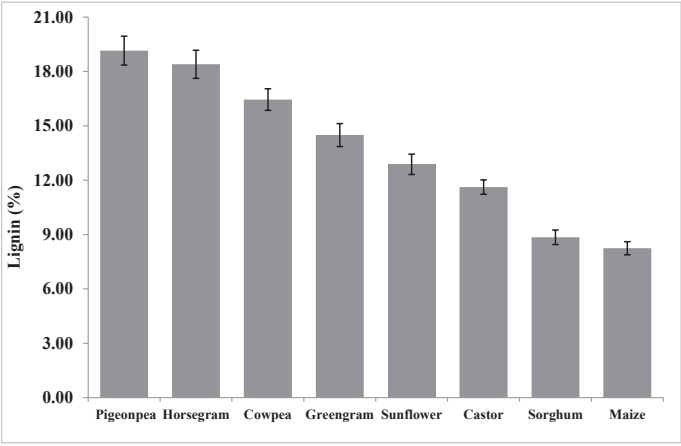

Fig. 1 : Crop wise lignin content of roots (mean of 2 cultivars) in descending order

While all the constituents influence decomposition, residue N content and lignin content exert the greatest control over the decomposition process. Residue N concentration (and consequently C/N ratio) is an important parameter determining decomposability due to the influence of N availability on microbial metabolism (Parton *et al.*, 2007). Plant residues with a high C/N ratio are mineralized far more slowly than residues with low C/N ratio. However, over a wide range of plant materials, C/N ratio was found to be poorly correlated with litter decomposition (Wang *et al.*, 2004; Jalota *et al*., 2006). The lignin to N ratio, which integrates the effects of the two most important characteristics governing plant residue decomposition, has been proposed as a better indicator of chemical recalcitrance than lignin content alone and has been used extensively to distinguish plant residues that are difficult to degrade, *i.e.* high lignin/N ratio, from those that are more easily biodegraded, *i.e*. low lignin/N ratio (Moore *et al.*, 1999; Parton *et al.*, 1987; Paustian *et al.*, 1992). In the present study, lignin/N ratios of roots were 2-3 times higher than those of shoots (Table 3). The high lignin/N ratios of roots make them more difficult to decompose because not only is the carbon of lower quality due to higher lignin content, but also nitrogen that soil microorganisms require is in short supply.

Decomposition behaviour

Due to the higher content of lignin in roots, root residues decompose more slowly than above ground biomass and therefore have greater influence on long term soil organic matter buildup. In this study, the decomposition or carbon mineralization patterns of roots and shoots were exponential in nature, being faster in the initial stages and slowing down with the passage of time (Figure 2). Regardless of crops and cultivars, roots exhibited distinctly slower or lower carbon mineralization than their corresponding shoots. Per cent added C mineralized at the end of 120 days of incubation was markedly lower for roots than their corresponding shoots.

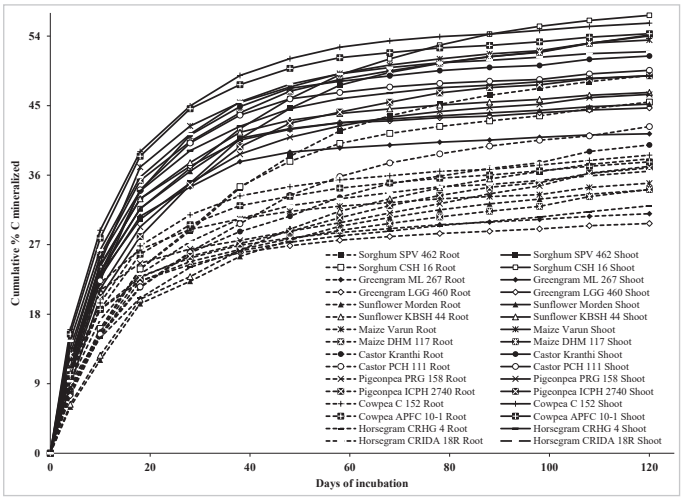

Fig. 2 : Cumulative % C mineralized from root and shoot material of crops and cultivars during 120 days of incubation

Averaged across crops and cultivars (means not shown), per cent C mineralized in 120 days was 37.35% in roots and 50.22% in shoots. These results clearly indicate that roots decompose much more slowly than shoots in soil. Numerous studies conducted under different conditions confirm the slower mineralization of root C (Bolinder *et al.*, 1999; Puget and Drinkwater, 2001; Lu *et al.*, 2003). Jalota *et al.* (2006)

found that for each 10% increase in lignin concentration, the proportion of the plant materials decomposed decreased by 25%. Abiven *et al.* (2005) observed slower decomposition of roots, which had higher lignin content, compared to leaves and attributed this to the presence of the suberin-lignin complex in root tissue.

Correlations were worked out between % C mineralized in 120 days and relevant residue quality parameters. Lignin showed the best correlation (r = -0.684**) followed by lignin/N (r = -0.636**), both of which had a highly significant (p = 0.01) negative relationship with % C mineralized (Figure 3). Cusack *et al*. (2009) also reported a significant negative correlation between lignin content and decomposition rate of roots. In litter bag studies of roots of temperate desert vegetation in China, Zhao *et al.* (2015) found that the loss of root litter was strongly controlled by the initial lignin content and the lignin:N ratio, as evidenced by the negative correlations between decomposition rate and litter lignin content and the lignin:N ratio, suggesting that root litter quality may be the primary driver of below ground carbon turnover. The strong negative relationship between C mineralized and lignin content in the present study suggests that roots, which have higher lignin content than shoots, decompose more slowly, and may contribute proportionately more to the formation of stable organic matter in soil.

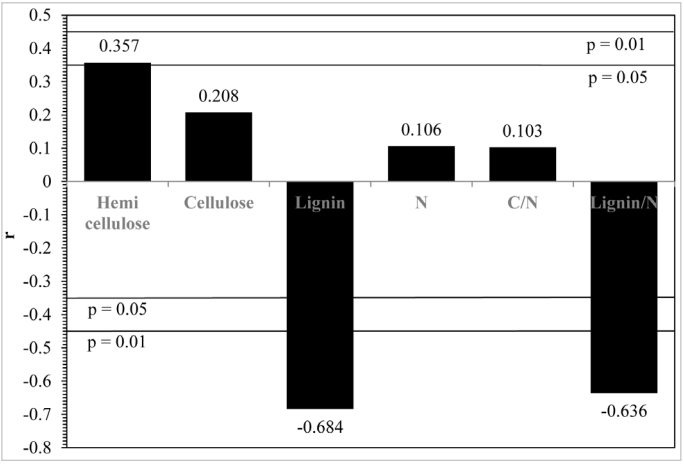

Fig. 3 : Pearson correlation coefficient 'r' between % C mineralized in 120 days and residue quality parameters

Conclusions

The results of this study bring out three key aspects - 1. root biomass of crops is substantial and roots make significant inputs of carbon to the soil, 2. roots contain greater proportion of recalcitrant constituents that make them intrinsically more difficult to decompose, 3. the rate of decomposition of root material in soil is slow. These features make roots potentially major contributors of stable organic matter in soil. Thus roots play a significant role in sequestering carbon in soil and therefore merit consideration in formulating strategies for carbon sequestration in soil in agroecosystems.

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