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RESEARCH ARTICLE

Assessing Carbon and Nitrogen Partition in *Kharif* Crops for Their Carbon Sequestration Potential

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Abstract A pot culture experiment was conducted to identify carbon sequestration potential among the crops such as maize, soybean, sorghum, pearl millet, finger millet and rice through estimating carbon (C) and nitrogen (N) partition in root and shoots. Plant biomass, C and N were measured and C:N, C:C, N:N, C:N ratio were calculated at 30, 50, 75, 90 DAS (days after sowing) and at crop maturity from each crop. Among the crops grown, total dry biomass was decreasing in the order of maize > pearl millet > sorghum > soybean > rice > finger millet. The highest plant biomass was recorded in maize crop (15.82 g/plant at 30 DAS and 44.28 g/plant at 90 DAS). There was a considerable variation observed in N:N, C:C and C:N ratio among the crops as well as at crop growth stages wise. The C:N ratio increased with crop growth from 30 DAS to crop maturity in all the crops. The C:N ratio among the crops at 30 DAS was varied from 27.53 (in soybean) to 69.66 (in rice). By balancing both plant biomass and C:N ratio, it was concluded that carbon sequestration potential of maize, sorghum and pearl millet was higher when compared to rice, finger millet and soybean.

Keywords Carbon · Carbon sequestration potential · Nitrogen · Plant biomass

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Introduction

Carbon (C) is a main energy source for soil microorganism, which is converting residues into plant available nutrients via soil humus [1]. It is an essential component of soil ecosystem, and responsible for chemical reactions, physical events and biological process. Soil organic carbon (SOC) increases in soil mainly due to incorporation of residues, and a net loss of soil C may increase atmospheric C as a green house gas [2]. Global scientist community is interested to know the characterization of soil C dynamics which require actual crop residue C entering into soil. This includes above ground plant parts such as stem and leaf and below ground parts like roots and exudates [3]. Agricultural soils may act as a sink or source of CO_2 depending on land management. They can potentially store some of the atmospheric CO_2 fixed by crop plants and hence mitigate greenhouse gas emissions from the agricultural sector. The Plant root exudates contributing significant amount of C to soil. The exudates play an important role in C flow in the soil–plant system; 16–33 % of the C assimilated by plants through photosynthesis is transferred into the soil through the roots [4]. Soil organic carbon and nitrogen (N) have long been identified as factors that are important to soil fertility in both managed and natural ecosystems [5]. The rhizodeposit C constitutes 40 % of the total root-derived C [6]. The root residues account for about 50 % of the SOC pool [7]. In plants, 1.5–3.0 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 aboveground residues [8]. On average, a whole corn plant at physiological maturity contains 436 kg C per 1,000 kg dry matter, distributed as follows: 26.6 % in the leaves, 24.5 % in the stem, 32 % in the grain, 7 % in the roots, and 9.8 % in the cob [8]. About 7.7–20 % of the corn shoot residues are retained in the SOC pool in long-term field experiments [9]. The amount of SOC that exists in any given soil is determined by the balance between the rates of organic carbon input (vegetation, roots) and output (CO_2 from microbial decomposition).

Indian soils are deficient in nitrogen and carbon (nearly 62 %). These can be increased by two ways; (1) addition of fertilizers (2) use of crop residues. The first way may increase cost of production and deteriorate soil quality in long run, but in the second case plant biomass of various crops can be used as a crop residues and proper management practices of them maintain the sustainability of soil for longer duration. If nitrogen content in plant part is known, predict nutrient supply through plant biomass at various time intervals can be predicted by using different models which are used to predict the biomass availability and nutrient supply. Therefore, a study was undertaken to provide quantitative estimates of C and N mass in plant parts and the ratios of N:N, C:C and C:N ratios in root and shoots of *kharif* crops viz. maize, soybean, sorghum, pearl millet, finger millet and rice at various time intervals for accounting carbon sequestration potential of these crops.

Materials and Method

The pot culture experiment was conducted using six crops; maize, soybean, sorghum, pearl millet, finger millet and rice during *kharif* season of 2011-12 in Glass Screen House of Division of Environmental Soil Science, Indian Institute of Soil Science (IISS), Bhopal, India. The surface soil (0–15 cm) was collected from IISS field for experimentation. The soil was clay loam in texture with pH(1:2.5) 8.06; EC (dSm^{-1}) 0.57; organic carbon 0.44 %; available N 175 kg ha^{-1}; available phosphorus (P) 7.53 kg ha^{-1}, available potassium (K) 185 kg ha^{-1}, available sulphur 9.1 kg ha^{-1} and diethylene triamine penta acetic acid (DTPA) extractable zinc (Zn) 0.46 ppm. Initial soil was analyzed by following standard methods of analysis [10]. The processed soil was filled in 90 pots @ 10 kg/pot. Five crops (maize, soybean, sorghum, pearl millet, finger millet) were grown and rice seedlings were transplanted in each pot in a manner that each treatment should be replicated for three times. Fertilizers were applied @ 100:60:60 of N, P_2O_5 and K_2O (kg/ha) for sorghum, rice, maize and pearl millet; 30:60:40 of N, P_2O_5 and K_2O (kg/ha) for soybean and 60:40:40 of N, P_2O_5 and K_2O (kg/ha) for finger millet. These fertilizers were applied through urea, di-ammonium phosphate (DAP) and muriate of potash (MOP). Half dose of N and full dose of P and K were applied at the time of sowing in rice, maize, sorghum, pearl millet and finger millet as basal dose and the remaining dose of nitrogen was applied as two equal splits at 30 and 60 DAS. In soybean, all the nutrients were applied at the time of sowing as basal dose. Zinc sulphate (10 kg/ha for rice and 7 kg/ha for other crops) was applied at the time of sowing.

Plant samples were collected at different time interval viz. 30, 50, 75, 90 DAS and at crop maturity for analysis. At every sampling stage one plant uprooted from each pot and washed with distilled water and collected in paper bags. The plant (root and shoot) parts were separated with the help of scissors and stored in separate paper bags. The plants in paper bags were further allowed to air dry for 2–3 days and then placed in hot air oven at 60 °C for 24 h. Dry matter of shoot and root were recorded and total nitrogen and, total carbon were estimated with the help of CN analyzer model FLASH 2000 organic elemental Statistical analysis was done for complete randomized design [11].

Results and Discussion

Plant Biomass

Data pertaining to plant biomass (root and shoot) was presented in Table 1. It was clear from the results that total plant biomass was increasing with plant growth period from initial crop growth to 90 DAS and thereafter it declined at crop maturity stage in all the crops but the amount and rate of accumulation of biomass varied among the crops at various growth stages. During the course of investigation total plant biomass of maize, pearl millet, sorghum, rice, finger millet and soybean varied between 15.82–39.91, 10.75–33.86, 7.46–28.6, 4.14–21.8, 3.53–21.5 and 4.56–17.29 g, respectively.

Total plant biomass was recorded highest at 90 DAS in all crops. Root and shoot biomass varied widely among the crops at different growth stages. The maximum per cent increase in biomass was recorded at 90 DAS. After 90 DAS shoot biomass was slightly declined but root biomass increased from initial to final crop growth stages for all the crops. The root biomass varied in maize 6.40–10.64 g, pearl millet 4.00–8.24 g, sorghum 1.27–5.18 g, rice 1.72–6.14 g, finger millet 1.41–6.08 g and soybean 1.27–3.51 g. Several studies indicated that soil N availability, although strongly altering shoot growth, does not significantly affect the dynamics of root growth at depth [7]. Among all crops, maize crop contributed maximum root biomass (10.64 g) followed by pearl millet, rice, finger millet, sorghum and soybean crops. The balance fertilizer enhanced the carbon sequestration rate, and was more in maize-wheat cropping system [12]. The above result also fulfill the hypothesis of growth curve, in which plant attained maximum biomass and after it slightly decline [13, 14].

Table 1 Plant biomass (g/plant) at different time interval

Crop	Time interval (DAS)														
	30			50			75			90			Crop harvest		
	S	R	T	S	R	T	S	R	T	S	R	T	S	R	T
Sorghum	6.20	1.27	7.47	12.16	2.84	15.00	19.24	3.20	22.45	27.67	4.20	31.87	23.44	5.18	28.62
Soybean	3.30	1.27	4.56	3.46	1.85	5.30	9.58	1.54	11.11	18.00	2.54	20.54	13.77	3.51	17.29
Rice	2.41	1.72	4.14	5.43	3.13	8.56	11.55	4.16	15.71	19.96	5.16	25.13	15.74	6.14	21.88
Maize	9.42	6.40	15.82	20.09	7.63	27.71	26.21	8.66	34.86	34.63	9.66	44.28	29.27	10.64	39.91
Pearl millet	6.75	4.00	10.75	15.31	5.23	20.54	21.43	6.26	27.69	29.85	7.26	37.11	25.62	8.24	33.86
Finger millet	2.12	1.41	3.53	5.11	1.57	6.68	11.23	4.10	15.33	19.65	5.10	24.75	15.42	6.08	21.50
CD ($P = 0.05$)	1.58	0.55	1.83	4.91	0.75	4.62	5.11	0.55	4.90	5.11	0.55	4.90	4.84	0.55	4.70

S shoot, *R* root, *T* total

Table 2 Nitrogen ratio, carbon ratio between root and shoot and C:N ratio at different crop growth time interval

Crop	Time interval (DAS)														
	30			50			75			90			Crop harvest		
	N:N	C:C	C:N	N:N	C:C	C:N	N:N	C:C	C:N	N:N	C:C	C:N	N:N	C:C	C:N
Sorghum	0.40	0.93	65.7	0.41	0.96	65.2	0.42	0.93	65.9	0.25	0.98	85.2	0.13	0.99	85.6
Soybean	0.37	0.99	27.5	0.24	1.02	28.1	0.33	1.06	31.8	0.32	0.93	33.6	0.31	0.92	33.9
Rice	0.44	0.94	69.7	0.33	0.96	75.7	0.23	0.94	81.3	0.24	0.97	84.1	0.25	0.93	84.5
Maize	0.31	0.94	51.0	0.23	1.04	53.4	0.27	1.05	57.1	0.26	0.89	56.8	0.20	0.94	57.2
Pearl millet	0.42	0.95	50.4	0.25	0.99	58.3	0.27	0.98	59.1	0.13	0.94	65.5	0.11	1.04	65.9
Finger millet	0.46	0.96	65.4	0.39	0.98	68.4	0.29	0.94	75.1	0.24	1.03	81.7	0.25	0.98	82.1
CD ($P = 0.05$)	0.017	0.009	0.34	0.064	0.009	0.37	0.020	0.010	0.45	0.022	0.011	0.63	0.024	0.011	2.74

N and C:C Ratio in Root and Shoot

Nitrogen and carbon ratio between root and shoot were enlisted in the Table 2. The nitrogen ratio between root and shoot was increased from 30 DAS to 75 DAS and then after decreases in all the crops. In finger millet crop recorded maximum (0.46) N/N ratio followed by rice (0.44), pearl millet (0.42), sorghum (0.40), soybean (0.37) and maize (0.31) at 30 DAS. In initial stages plant take more amounts of nitrogenous substances to increasing plant biomass. In several species it has been observed that localized NO_3^- application induces root proliferation due to increased growth of laterals [15–17]. Carbon:carbon (C:C) ratio between root and shoot also varied widely. It was almost equal in all the crops at 30 DAS and increasing with increasing time interval. It was maximum in pearl millet crop (1.04) followed, sorghum (0.99), finger millet (0.98), maize (0.94), rice (0.93) and soybean (0.92) at crop maturity. Carbon content is more in non-legume crops in comparison to legumes. Carbon content increased with the crop growth. It may be due to cumulative increase in the accumulation of biomass through photosynthesis. Carbon is a structural element; it didn't show higher variation in different crop. It varied between 42 and 46 % in major crops [18].

C:N Ratio

The C:N ratio was considered as important parameter that controls the carbon sequestration potential of the crops. The C:N ratio was lower at initial stages and increased with growth period of the crops. The lower per cent increment in C:N ratio was observed between 30 and 75 DAS but it shot up at 90 DAS. It might be due to higher nitrogen uptake by crops at initially stages and low uptake at later stages and also total C accumulation was higher in the later stages. Different crops showed different C:N, it was varied between 65.7–85.6, 69.7–84.5, 5.4–82.1, 50.4–65.9, 51–57.3 and 27.5–33.9, in sorghum, rice, finger millet, pearl millet, maize and soybean, respectively (Table 2). Nitrogen and C assimilation and allocation in plant parts and between plants play a particular role in crop productivity. Therefore it is affected by nitrogen concentration in soil solution, plant species (C_3 or C_4) and climatic conditions [19]. Researchers suggested that, the impact of root proliferation on N uptake may be limited [20, 21] and more

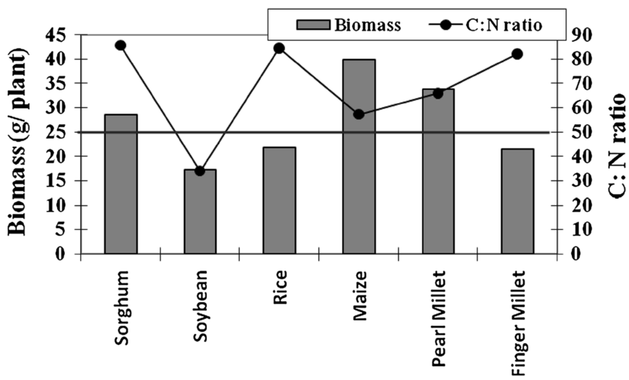

Fig. 1 Carbon sequestration potential of crops based on the threshold C:N ratio (50) and threshold plant biomass (25 g/plant)

critical for plant-to-plant competition in N uptake than for N uptake of a whole plant population such as a crop [22]. Carbon nitrogen ratios in plants are also affected by concentration of N in labile pool, crop growth pattern and plant species [23].

Carbon Sequestration Potential

Based on the C:N ratio and yield of the crop biomass, the carbon sequestration potential of a particular crop can be calculated [24]. The biomass with wider C:N ratio takes time for decomposition and slowly releases CO_2 to the atmosphere. It leads to increase in storage time of the C in soil. These data can also be used in many simulation models to compute the carbon sequestration potential of crops at particular crop growth stage [25]. The crops such as sorghum, rice and finger millet have the wider C:N ratio and lower crop biomass particularly below ground biomass. But in maize and pearl millet, it was vice versa (Fig. 1).

Balancing both plant biomass and C:N ratio, the crop having higher carbon sequestration potential was identified. By assuming, the crops which had C:N ratio more than the threshold C:N ratio (50) and plant biomass higher than the threshold biomass (25 g/plant) were considered as having higher carbon sequestration potential. It is clear from the study, the carbon sequestration potential of maize, sorghum and pearl millet was higher as compared to rice, finger millet and soybean.

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