Research Article

Litter Decomposition and Nutrient Dynamics under variable soil substrates in *Populus deltoides* Agroforestry System in the Tarai tract of Uttar Pradesh

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Abstract

The study investigated the quantity of litter fall, its chemical composition, nutrient addition, dynamics and effect of climatic variables on decomposition under agroforestry systems involving poplar clones (G-48) intercropped with cash crops (mentha, mustard and urd) in the tarai tract of Uttar Pradesh, India. Considerable amount of nutrients were recycled to the soil through litter fall of poplar (*P. deltoides*). Availability of low cost organic soil amendments like agrichar, farmyard manure (FYM) *etc*. accelerate the litter decomposition rates. The correlation matrix was significant (R^2>0.9) between litter weight loss and time factor under nutrient/climatic variables during different stages of decomposition under organic amendments in soil.

Keywords: Litterfall, Nutrient dynamics, Agrisilviculture system, Climatic variables, Agrichar

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Introduction

Plant litter fall plays an important role in improving the soil physical properties, increasing nutrient availability and enhancing biological activities [1, 2] in the existing natural or anthropogenic ecosystems. The organic material enrichment in the soil through decomposition and mineralization depends on the quality of litter [3, 4] litter input [5], species composition, leaf morphology, type of vegetation [6, 7], prevailing climatic conditions and foliar chemical variables [8]. Generally, leaf litter quality is higher and rate of decomposition is more rapid on fertile soils. Soils treated with organics accelerate the decomposition rate which may help in enhancing soil nutrient availability; thereby promoting the growth of decomposers (microorganisms) affecting the rate of litter decomposition [9]. Microorganisms decrease the external losses of nutrients and make efficient use of nutrients from organic and inorganic sources of the soil. Litter quality and site edaphic conditions are most important factors for small areas [10], whereas climatic conditions play a more prominent role at larger spatial scales in controlling litter decomposition [11].

Poplar intercropping with crops like pearl millet, sorghum, wheat, rice, pulses is quite common in northern parts of the country because of fast growing period and multi-utility in the industrial sector and better economic returns. Prominent agroforestry systems existing in different agro-climatic regions of India are agrisilviculture and agrihorticulture in western and eastern Himalayan regions; agrihorti-silviculture in the upper and trans-Gangetic plains, and agrisilviculture and silvipastoral system in the southern plateau and hilly regions *etc.* Poplar covers a wide area in northern and eastern India [12]. In India, nearly, 312000 ha area is under *P. deltoides* plantation, out of which 60% is block plantation and 40% bund plantation [13]. Poplar (*P. deltoides*) is winter deciduous fast-growing vegetative propagated tree species [14], which produces maximum litter in a single flush (November and December) and recycle nutrients fast [15, 16]. Poplar being shallow rooted contributes more root biomass to soil. Therefore, litter fall and fine roots contribute in substantial biomass accumulation and maintain the soil fertility through nutrient cycling [17]. It also contributes to local communities through additional income source and produce raw material for plywood and match-spint industries, packing cases *etc*. [18], sequester carbon and mitigate CO_2 from atmosphere [19-21]. Understanding the decomposition and nutrient release pattern of litterfall helps in managing the litter inputs. Decomposition rate is increased in organic rich soils. Addition of external organics and rapid litter decomposition aids in maintaining the fertility of intensively cultivated soils of northern India. Agrichar, partially burnt rice husk is a by-product of rice mills available in abundance in northern parts of the country and is potential organic amendment source for soil nutrient restoration. *P. deltoides* agroforestry system is more prominent in this region and the study on relation between litter decomposition under variable amendments and climatic conditions has not been carried out earlier. Therefore, the work was conducted to study the litter decomposition and nutrient dynamics from poplar clones (G-48) under variable soil nutrient availability.

Materials and Methods
Site description

The field experiment was conducted at agricultural land in Bilaspur, distt. Rampur, 30 km from Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (**Figure 1**). Geographically, the study area is a tarai land adjacent to the outer Shiwalik range of the Himalyan mountains and lies between 28.098 N latitude, 79.244 E longitude and at an altitude of 274 m above the mean sea level. The weather parameters like minimum and maximum temperature, relative humidity, rainfall and sunshine hours during the period of the experimentation were recorded at the Meteorological Observatory of the Norman E. Borloug Crop Research Centre, Pantnagar from December, 2010 to September 2011 (**Figure 2**). Surface soil of the study site was silty and loamy, having pH 6.73, EC 0.69 dS m^{-1}, OC 0.89%, available N 141.24 kg ha^{-1}, available P 23.65 kg ha^{-1}, and available K 148.04 kg ha^{-1}.

Figure 1 Location of the experimental site, Bilaspur, Uttar Pradesh

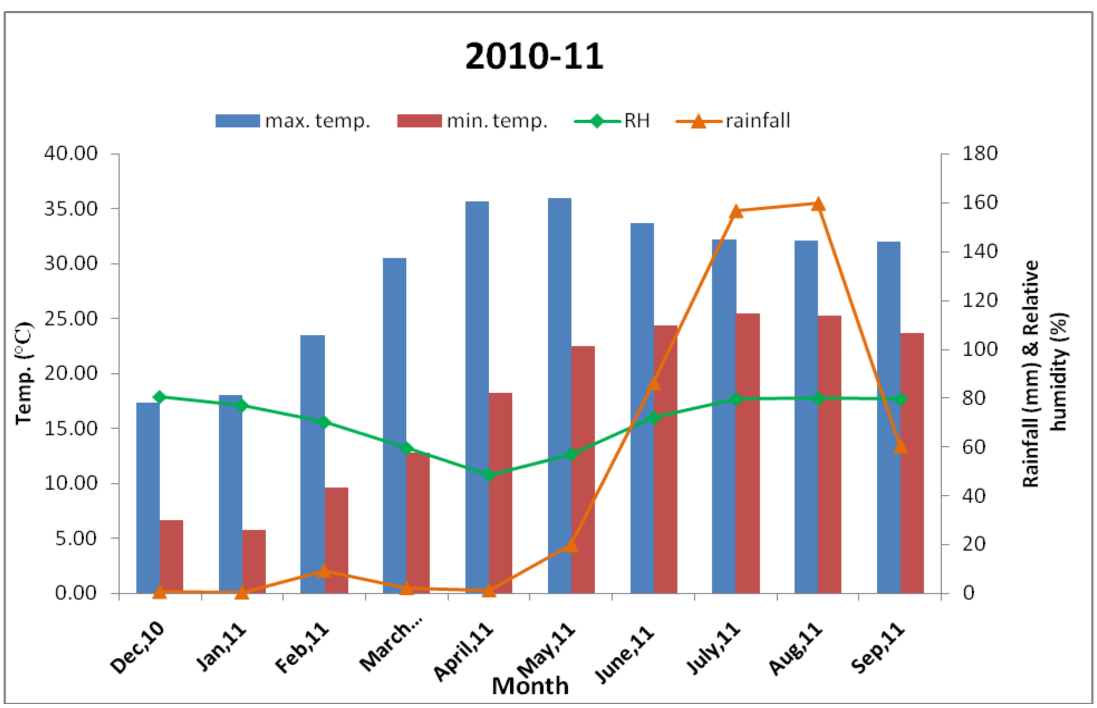

Figure 2 Meteorological data for the year 2010-11

Experimentation and treatments

The field experiment under agrisilviculture system was laid down in randomized block design with three replications. The plot size for each treatment was 3×2 m with 0.5 m plot spacing. Litter decomposition study was done under three different organic treatments/soil substrates with control *viz.*, 100% agrichar (A_{100}) (50 t ha^{-1}), 100% FYM treatment (F_{100}) (50 t ha^{-1}), 50% agrichar + 50% FYM treatment (A_{50}+F_{50}) (25 t ha^{-1} (agrichar)+ 25 t ha^{-1} (FYM) and control (C_0) applied once before initiation of experiment. The Agrichar (agro-industrial waste) was collected from local rice mill and farm yard manure from nearby village and was analyzed in laboratory before application in the field. The organic amendments are rich source of carbon and nitrogen. *Populus deltoides* clone (G-48) samplings were collected from agro-forestry centre of the University. The agrisilviculture system consisted of poplar (G-48) with *Mentha arvensis*, *Brassica nigra and Vigna mungo* intercropping. Litter bag technique [9] was used to study the pattern and rate of litter decomposition and nutrient release of *P. deltoides* clone (G-48). The leaf litter collected from experimental plots was filled in the nylon meshes of size 25 x 25 cm and placed for decomposition study in each plot separately. The litter bags were placed in the field from where the litter was collected for decomposition study (**Figure 3**). Three bags were retrieved from the field at 30-day intervals for 300 days and were brought to the laboratory. After proper litter sorting, samples were then oven dried at 65^0C to a constant weight for further analysis. Organic carbon was analyzed by Walkley and Black method, nitrogen by Kjeldahl's method, P and K content estimation in solution after decomposing the material in a mixture of concentrated HNO_3 and $HClO_4$ in the proportion of 9:1 by volume. Phosphorus content was analyzed colorimetrically, potassium and sodium content by flame emission spectrometry**.** Water soluble compounds (WSC) were estimated by overnight soaking of 1.0 g litter sample in 100 ml of distilled water for 24 hrs. Then the suspension was filtered, the residue dried and the loss in weight was calculated [22].

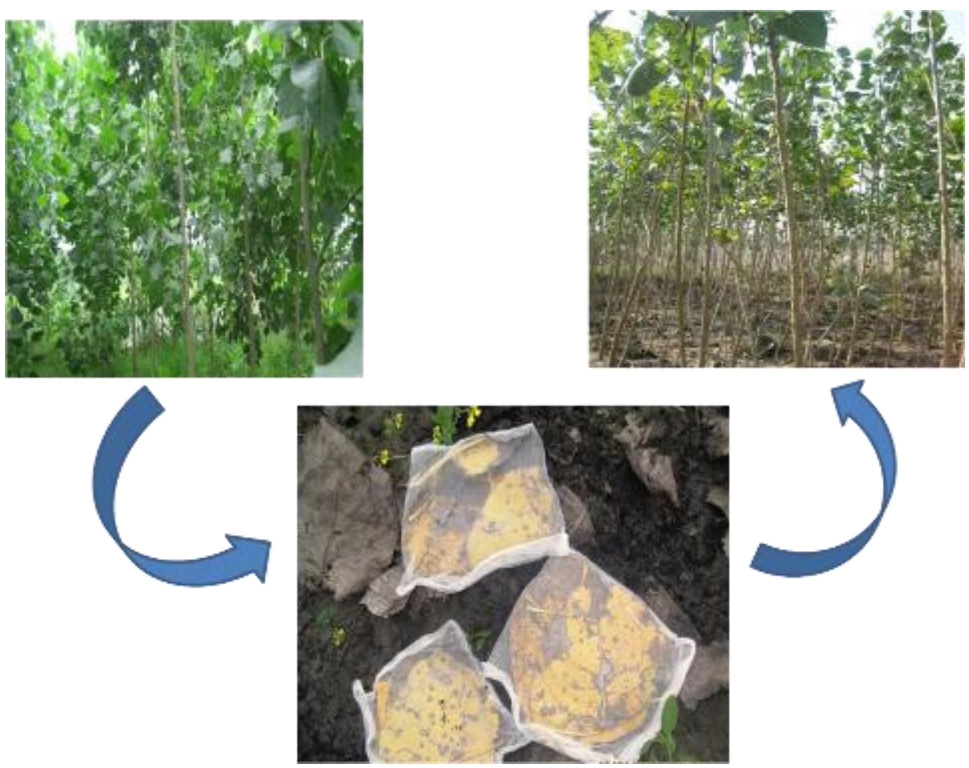

Figure 3 Litter collection and field decomposition of *Populus deltoides*

Results and Discussion

Temporal leaf Litter decomposition under different organic treatments

The time series data on percent weight remaining and cumulative weight loss (%) of litter material (**Figure 4**) filled in prepared litter bags has been used to determine the pattern of decomposition along with changes in nutrient content. Results showed that the decomposition of leaf litter was fastest in soil treated with F_{100}. Almost complete decomposition (98.96%) was observed in ten months while in other treatment plots, the values were 96.88% for A_{100} treatment, 97.56% for A_{50}+F_{50} treatment and 89.32% in C_0. Soils treated with organics accelerate the decomposition rate and promotes the growth of the decomposers (microorganisms) [9].

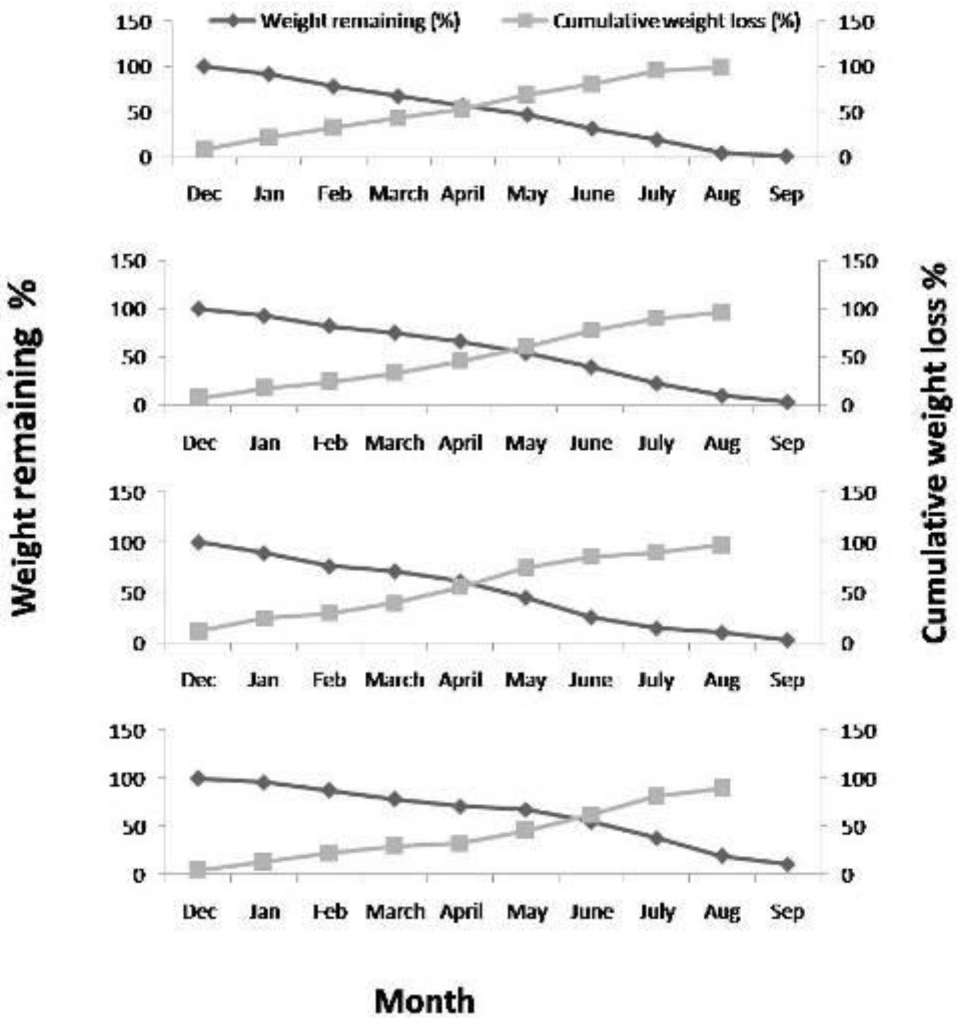

Figure 4 Remaining weight (%) and cumulative weight loss (%) in litter bags with time in treatment (a) A_{100}, (b) F_{100}, (c) A_{50}+F_{50} and (d) C_0 (a-d above to below)

For *P. deltoides*, leaf litter decomposition was slow in early decomposing months, *viz* January, February and March. About 24.84 % (w/w) litter degraded during initial three months of study in A_{100}. In other treatment sites, the percent decomposition was 33.12% (F_{100}), 28.88% (A_{50}+F_{50}) and 21.72% for control. The slow decomposition might be due to low temperature. Other researchers observed that the rate of decomposition of rice straw in the litterbags buried in wheat fields depended on temperature [23]. Slow decomposition in control plot might be due to restricted microbial growth in the absence of substrate source. Decomposition in the month of April also accounted a slow decomposition. By the end of the month of April, 33.80% (A_{100}), 43.12% (F_{100}), 39.12% (A_{50}+F_{50}) and 29.32% (C_0) litter was degraded under low soil moisture content. In the month of May and June, the rate of decomposition was accelerated and the percent decomposition accounted was 60.48% (A_{100}), 68.44% (F_{100}), 74.64% (A_{50}+F_{50}) and 45.32% (C_0). It was observed that 60-75% litter was decomposed in treated soils whereas a slow decomposition was observed for control. This might be due to favourable soil temperature and moisture conditions in the soil. The monthly decomposition rates were generally higher in rainy season (July to August) in the present study. In the month of July, the decomposition percent was 77.52% (A_{100}), 80.88% (F_{100}), 85.76% (A_{50}+F_{50}) and 61.92% (C_0). Further, in August degraded matter percent raised to 90.20% (A_{100}), 95.64% (F_{100}), 90.12% (A_{50}+F_{50}) and 80.84% (C_0). Similar findings were reported on forest litter, sal, teak, eucalyptus and poplar, mangium (*Acacia mangium*) *etc*. [24, 25]. Only 3-5% of the total matter was left for decomposition after September in all the treatment plots whereas in control plot about 11% litter was left not decomposed.

To assess the temporal pattern of decomposition, the time series data on percent weight loss of leaf liter was used in regression analysis. Thus, the functions of the system can be formalized in the form of regression equation. The correlation between weight loss and time factor was significant (R^2>0.9) and direct relationship between weight loss and time factor was observed (**Figure 5**). Namgung *et al.* (2008) [26] reported that *Q. variabilis* and *P. densiflora* leaf litter lost by 54.5% and 41.9%, respectively, after 30 months decomposition. Vaieretti *et al.* (2005) [27] found that the rapid and slow phases of decomposition are controlled by labile components that increased from the litter from subsequent months after the start of the study. The mean relative rate of litter decomposition increased with the time. Similar observations were recorded by other researchers [28-30] while studying the litter decomposition pattern of *D. sissoo*, *E. globules* and *D. strictus*.

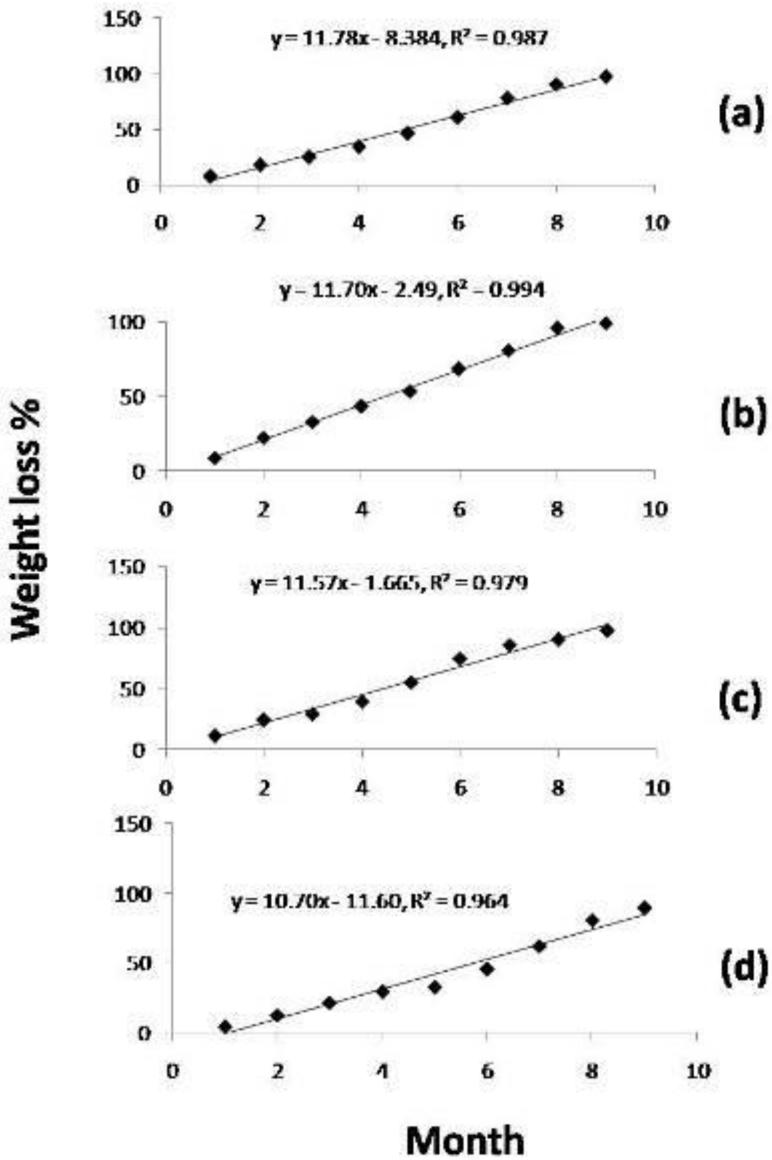

Figure 5 Litter decomposition under (a) A_{100}, (b) F_{100}, (c) A_{50}+F_{50} and (d) C_0
(* = significant at 0.01 probability, Where Y = percent weight loss)

Effect of climatic variables on litter decomposition

Climate is the primary determinant of decomposition [31] that affects the rate and pattern of decomposition of litter [32, 33]. The weight loss and amount of rainfall were positively correlated and depicted direct relationship between rainfall and weight loss of litter mass (**Table 1**). Greater weight loss during the rainy season might be due to higher soil moisture and temperature and leaching of water-soluble substances from the litter mass. This is obvious from the positive correlation between the rate of weight loss with temperature and rainfall (**Table 2**) [34, 35]. Among abiotic environmental factors, temperature and rainfall are most critical in governing the rate of decomposition [36]. Other studies [37] observed highest decomposition rate of *Ochlandra* (reed bamboo) in rainy season and its strong positive correlation with the rainfall and soil moisture. Similar positive relationship of rainfall and monthly mass loss for leaf litter decomposition study of six multipurpose tree species including *D. sissoo* in Central Himalaya was observed [28]. Similarly, maximum mean relative decomposition rate of *E.* hybrid litter in rainy season and minimum during summer signifying the importance of rainfall for decomposition of litter mass was found [33].

Table 1 Litter decomposition under different climatic attributes

Treatment	Climatic attribute		
	Rainfall	**Temperature**	**Relative humidity**
A_{100}	$Y = 0.437X_1 + 23.38$; $R^2 = 0.643$*	$Y = 4.221X_1 – 53.79$; $R^2 = 0.685$*	$Y = 1.431X_1 – 53.42$; $R^2 = 0.203$
F_{100}	$Y = 0.435X_2 + 28.41$; $R^2 = 0.616$*	$Y = 4.489X_2 – 55.14$; $R^2 = 0.750$*	$Y = 1.235X_2 – 34.91$; $R^2 = 0.146$
$A_{50}+F_{50}$	$Y=0.443X_3 + 28.17$; $R^2 = 0.642$*	$Y=4.470 X_3 – 54.54$; $R^2 = 0.746$*	$Y=1.344X_3 – 42.3$; $R^2 = 0.174$
C_0	$Y=0.378 X_4 + 18.58$; $R^2 = 0.594$*	$Y=3.594X_4 – 46.8$; $R^2 = 0.612$*	$Y=1.314X_4 – 53.08$; $R^2 = 0.211$

* = significant at 0.01 probability
Where Y = loss in weight (%) and X_1, X_2, X_3 and X_4 are the change in climatic attribute for different treatments respectively.

Table 2 Correlation matrics between litter and nutrient dynamics in different treatment plots

	OC in soil	**OM in soil**	**Wt. loss%**	**WSC (leaf)**	**N% (leaf)**	**C/N (leaf)**	**P%**	**K%**	**Atm Temp.**	**Rain fall**	**Rel. Humidity**
OC in leaf	ns	ns	-0.99**	0.98**	0.941**	-0.71*	0.99**	0.94**	-0.82**	-0.71*	ns
OC in soil		0.88**	ns	ns	ns	ns	ns	ns	ns	ns	-0.73*
OM in soil			ns	ns	ns	ns	ns	ns	ns	ns	-0.73*
Wt. Loss %				-0.98**	-0.96**	0.77**	-0.99**	-0.96**	0.87**	0.785**	ns
WSC (leaf)					0.91**	-0.68 *	0.99**	0.97**	-0.87**	-0.736 *	ns
N% (leaf)						-0.89**	0.94**	0.87**	-0.79**	-0.837**	ns
C/N (leaf)							-0.75 *	ns	ns	0.936**	0.72*
P%								0.94**	-0.83**	-0.781**	ns
K%									-0.96**	-0.684*	ns
Atm. Temp.										ns	ns
Rainfall											0.63*

Highest intensity of organic matter decomposition under moderate temperature (about 30^0C) was found in similar researches [38]. Differences in litter decomposition rate at various altitudes, due to variation in temperature were reported [39]. Comparison of litter decay beneath natural stands at various elevations concluded that there was an average decrease in breakdown of nearly 2% for each 1^0 C drop in mean temperature [40].

Relative humidity regulates the soil moisture as due to high relative humidity evaporation is minimized thus soil moisture is maintained. While, low relative humidity favours the evaporation of soil moisture, adversely affecting the activity of microbes. Similar research found that the number of microbes reached their maximum during rainy season on the decomposing leaves of *Dendrocalamus* [41]. Relative humidity is indirectly related to litter decomposition as it affects the vicinity temperature [42]. Decomposition is inhibited in very dry soils because bacteria and fungi dry out and slow in very wet soils because anaerobic conditions develop in saturated soils. Decomposition proceeds at faster rate at intermediate water contents. Based on several other publications, it was concluded that the highest intensity of organic matter decomposition was observed with the soil moisture content of about 60-80% of its maximum water-holding capacity [38].

Temporal changes in nutrient concentration during decomposition of P. deltoides (G-48) litter

The decomposition of *P. deltoides* clones (G-48) was observed faster and changes in nutrient concentration was observed (**Table 3**). There was decrease in carbon (%) content of decomposing leaves in all the treatment plots during the study period. The rate of decrease in the first month was highest in A_{100} (16.28%) >F_{100} (15.64%)>$A_{50}+F_{50}$ (7.99%) and C_0 (5.20%). The rate of decrease of carbon for leaf litter of all treatments was increased in the subsequent three months. After that, due to climatic factors the rate decreased, but there was net continuous decrease in carbon content with the time elapsed. In the months of June and July, almost 50% of the carbon was lost in almost all the treatments. This may be due to favourable soil temperature and moisture. By the end of September, approximately 80% of the carbon was decomposed.

There was continuous increase in nitrogen content (Table 3) in all the treatments with increase in the decomposition time; however the rate of increase was higher during initial two months. Increase of rate of leaf litter decomposition resulted in decreased N content in the leaf (Table 2). During the first two months, the nitrogen content increased from 1.142% to 1.218% in A_{100}, 1.149% to 1.233% in F_{100} amended soils, 1.129% to1.102% in $A_{50}+F_{50}$ and 1.122% to 1.194% in C_0. There was continuous increase in nitrogen content for the first four months followed by slow decrease up to the end of decomposition period. The absolute amount of N and N released from the litter mass indicates initial immobilization of N during the first two months. This may be ascribed to increased microbial activity.

Initial immobilization of N by microorganisms during decomposition of the litter of various tree species has been observed earlier too [43].

Table 3 Litter and nutrients remaining in litterbags during different stages of decomposition in different treatment plots (December, 2010-September, 2011)

Treatment	December	January	February	March	April	May	June	July	August	September
g/bag left										
T1	25	23.15	20.56	18.79	16.55	13.47	9.88	5.62	2.45	0.78
T2	25	22.85	19.43	16.72	14.22	11.67	7.89	4.78	1.09	0.26
T3	25	22.28	19.02	17.78	15.22	11.23	6.34	3.56	2.47	0.61
T4	25	23.98	21.88	19.57	17.67	16.91	13.67	9.52	4.79	2.67
OC%										
T1	55.34	46.33	43.56	40.24	37.13	34.78	30.54	26.21	20.65	14.22
T2	54.67	46.12	43.01	39.34	35.67	31.45	26.43	22.45	17.34	9.32
T3	53.22	48.97	44.78	41.32	38.44	34.56	28.95	23.61	19.67	10.45
T4	52.16	49.45	45.72	42.78	39.02	35.66	30.32	25.45	20.63	15.35
N mg/bag										
T1	285.56	293.45	304.67	275.66	261.95	190.43	129.52	92.31	74.73	50.55
T2	287.42	297.22	308.32	273.21	258.52	185.92	116.44	72.94	61.72	32.21
T3	282.45	291.44	302.35	275.52	263.71	198.66	125.94	104.32	72.26	52.32
T4	280.56	289.82	298.71	278.58	269.55	203.24	134.21	113.89	78.55	54.21
P mg/bag										
T1	40.45	36.44	32.62	28.09	25.82	19.34	15.61	13.76	10.31	9.48
T2	41.93	35.54	31.21	29.34	26.33	21.55	16.43	12.56	10.01	8.14
T3	38.34	36.76	32.78	30.21	26.92	22.52	17.54	14.32	11.33	8.67
T4	37.74	35.44	33.21	31.45	27.04	23.62	18.98	13.33	11.27	9.79
K mg/bag										
T1	204.26	187.32	146.67	107.54	85.44	63.76	44.85	36.54	28.95	23.45
T2	200.62	180.76	142.43	102.42	74.52	57.63	40.73	32.54	24.65	20
T3	196.37	178.62	145.58	106.49	78.41	62.21	44.44	35.42	27.43	24.55
T4	195.79	179.84	158.43	112.01	80.09	67.92	47.54	37.55	28.64	25.67
C/N ratio										
T1	48.45	39.47	35.74	36.49	35.44	45.66	58.95	70.98	69.08	70.33
T2	47.55	38.79	34.87	36.00	34.49	42.29	56.75	66.86	66.98	58.25
T3	47.11	42.01	37.03	37.49	36.44	43.49	57.47	56.58	68.05	49.93
T4	46.48	42.66	38.26	38.39	36.19	43.86	56.48	55.87	65.66	70.79
WSC %										
T1	48.54	36.02	32.61	28.78	24.44	19.09	15.37	10.41	7.31	5.98
T2	49.76	38.24	32.83	30.57	25.86	21.31	16.58	12.63	8.93	7.29
T3	48.09	35.57	31.16	27.33	23.09	19.64	14.92	9.56	7.86	5.53
T4	50.15	36.93	34.82	31.69	27.75	21.44	17.98	11.72	8.62	8.29

T1= 100% agrichar, T2= 100% FYM , T3= agrichar (50%)+ FYM (50%), T4= control

C/N ratio is another index that conceptually expresses N concentration in organic matter, and gives a good relationship to mass loss in the early stage. Researchers have found that decomposition of leaf litter can be predicted by the C: N ratio [44]. *P. deltoides* leaves exhibit high initial C/N ratio and these values tended to slightly decrease with time. This was related to the low N content of poplar. Its dynamic descends until 150 days, then increases, and finally decreases again by the end of the study. Initially, the C/N ratio varied from 46-49 which gradually decreased in first two months. An increase was noticed from May and by the end of the study, it gradually decreased. Initial decomposition rate is promoted by high N concentration and low C/N proportion [45], but N retards long-term decomposition through inhibition of lignin-degrading enzymes and reactions that produce recalcitrant aromatic products [46].

The P concentration (Table 3) of decomposing litter decreased slightly at successive months of decomposition. The release of P proceeded gradually and 36.17% P was released during initial four months of decomposition in agrichar amended soils. The P release in FYM amended soil was 37.20%, highest among all the treated soils after four months because of higher total P content of FYM. By the end of July almost 60-70% P was decomposed in all the treated soils including control. The release of P in the soil increased as decomposition of organic matter progressed (Table 2) [25]. The rate of P mineralization decreased after July and only 5-10% P content of leaf litter was released during last two months which may be ascribed to the slow release from resistant P fractions.

There was decrease in potassium content of leaf litter enclosed in litter bags during decomposition of *P. deltoides* leaf litter with time. Most of the K (60%) was released during initial four months in all the treatments including the control. By the end of the observation period, almost 90% of K was released from the leaf litter. This tendency has often been observed by other researchers. One of the research observed fastest release of K amongst N, P, K, Ca and Mg from decomposition of *P. deltoides* litter in the poplar forests in Uttar Pradesh [47]. A quick release of K from leaf litters of tree species [43] and from rice straw [23] was observed.

The water soluble components of leaf litter of all the treatment plots decreased with the progressing decomposition time period (Table 2). The decrease was most rapid in agrichar amended soils whereas other two amended soils also showed a similar trend but slightly slower in control plot. This might have happened due to increased microbial activity in organic amended soils. Most of the water soluble compounds were decomposed by the end of July. The water soluble compounds decreased from 48.54% to 5.98% in agrichar amended soils (100%), 49.76% to 7.29%, in FYM (100%) treated soils. For control soils, the decomposition was from 50.15% to 8.29%. Research work reveals that the rate of litter decomposition is markedly affected by the amount of water soluble compounds and leachable substances [36]. Decreasing trends in water soluble compounds was observed [48]. Rain fall helps in fast leaching of soluble compounds and the decay of easily degradable compounds and the tissues of litter thus reflecting faster weight loss [35].

Conclusion

Field studies indicate that poplar-based agro-forestry has the potential to increase nutrient content in intensively cultivated soils. Nutrient release and decomposition pattern is dependent on leaf morphology, climatic conditions and soil properties. Understanding the decomposition and nutrient release pattern of litterfall helps in managing the litter inputs. Availability of low cost organic soil amendments like agrichar, FYM *etc*. accelerate the litter decomposition rates due to the presence to organic carbon and nitrogen sources, thereby refurbishing the soils and increased soil productivity.

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