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Allelopathic interference of *Populus deltoides* with some winter season crops

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Abstract – The performance of some winter season crops, namely *Triticum aestivum*, *Lens culinaris*, *Phaseolus mungo*, *Avena sativa*, *Trifolium alexandrinum*, *Brassica juncea* and *Helianthus annuus* was studied in association with *Populus deltoides* under alley cropping practice in two sets of fields in Punjab, North India. In one, the parent soil was retained (S_p), while in the other, the parent soil was replaced with soil collected from an area devoid of *P. deltoides* trees (S_r). Germination, plant height and biomass of the crops at 30 and 60 days after sowing (DAS) were reduced by 10 to 30% in both the *P. deltoides* fields compared to the ones without trees (S_c). The observed reduction was more pronounced in S_p fields than in S_r fields. Maximum reduction was observed in the case of *B. juncea* and least in *T. alexandrinum*. Germination and seedling growth of all the test crops except *A. sativa* and *T. aestivum* was found to be significantly reduced in response to the aqueous leachates of *P. deltoides* leaves. Likewise, the seedling length and dry weight of *L. culinaris* and *T. aestivum* were significantly reduced in litter amended soil. Litter and soil from *P. deltoides* fields were found to be rich in phytotoxic phenolics, the amount of which was more in S_p fields compared to S_r and control fields (S_c). Based on the study, the observed reductions could be attributed to the allelopathic interference of the tree with the crops through the release of phytotoxic phenolics from leaves and litter, which are continuously added to the soil.

agroforestry / *Populus* / winter crops / litter / phenolics / allelopathy

Résumé – Interférence allélopathique de *Populus deltoides* avec quelques cultures d'hiver. On a étudié dans deux groupes de champs du Punjab (Inde du Nord) les performances des cultures d'hiver suivantes associées avec des allées de *Populus deltoides* : *Triticum aestivum*, *Lens culinaris*, *Phaseolus mungo*, *Avena sativa*, *Trifolium alexandrinum*, *Brassica juncea* et *Helianthus annuus.* Dans l'un des groupes le sol d'origine a été conservé (S_p), tandis que dans l'autre il a été remplacé par un sol prélevé dans un endroit dépourvu de peupliers (S_r). La germination, la taille des plantes et la biomasse des cultures 30 et 60 jours après le semis ont été réduites de 10 à 30 % dans les deux groupes de champs comparativement aux champs sans peupliers (S_c). La réduction observée était plus forte dans les champs S_p que dans les S_r. La réduction maximum a eu lieu pour les cultures de *B. juncea* et, à un moindre degré, pour *T. alexandrinum*. Des filtrats aqueux de feuilles de *P. deltoides* ont réduit significativement la germination et la croissance des pousses de toutes les cultures testées, à l'exception de *A. sativa* et *T. aestivum*. De même, la longueur des pousses et le poids sec des cultures de *L. culinaris* et *T. aestivum* ont été significativement réduits dans le sol amendé par de la litière. Nous avons trouvé que la litière et le sol des champs de *P. deltoides* sont riches en substances phénoliques phytotoxiques ; les quantités sont plus importantes dans les champs S_p que dans les S_r et les témoins (S_c). Selon cette étude les réductions observées peuvent être attribuées à l'interférence allélopathique du peuplier avec les cultures par l'intermédiaire de substances phénoliques phytotoxiques provenant des feuilles et de la litière, qui s'incorporent continuellement au sol.

agroforesterie / *Populus* / culture d'hiver / litière / allélopathie / composé phénolique

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1. INTRODUCTION

Agroforestry is a type of land-use management system where woody perennials are deliberately mixed with crops and / or animals in spatial or temporal sequence so as to have both ecological and economical interactions between different components [12]. The concept of agroforestry is rapidly being converted from the traditional beliefs and practices into a fast-emerging science in the field of natural resource management. Since it combines the attributes of both forestry and agriculture, it is thought to provide a number of advantages to the sustainability of agroecosystems in terms of monetary gains, increased soil fertility, soil and water conservation, microclimate improvement (soil temperature, soil-water evaporation, humidity and irradiance), and weed control, leading to enhanced productivity. It is generally viewed as a merely beneficial practice but little emphasis has been given to the negative aspects like competition for water and nutrients [13], allelopathy [22, 24, 28] and over-shading. The information on qualitative analysis of positive tree-crop interactions is increasing fast with more studies coming up under a given set of geographical and climatic conditions. However, very few studies on negative interactions are available so far. In India, this practice of combining trees and crops gains more importance because of greater demand for food grains and resources to feed burgeoning population. Under this concept, a number of fast-growing multipurpose trees (both exotic and indigenous) have been introduced into agricultural fields with a view to increasing productivity. *Populus* spp. (largely *Populus deltoides* Bartr. ex Marsh.) is one such exotic tree being promoted on a large scale as alleys or windbreaks/shelterbelts. But recently, there have been reports that the growth and productivity of the wheat is reduced in the fields sheltered by *P. deltoides* and the observed reduction was due to the allelopathic interference of the tree [24, 25]. Allelopathy refers to the direct or indirect harmful effects (rarely beneficial) of one plant on the other through the release of the chemicals into the environment [19]. Keeping this in mind, the present work was undertaken to study (a) the performance of some winter season crops grown in association with *Populus deltoides* under the alley cropping system, and (b) to evaluate the allelopathic interference of *P. deltoides* with these crops.

2. MATERIALS AND METHODS

2.1. Collection of material

Healthy, pureline seeds of *Triticum aestivum* "PBW-215" (wheat), *Lens culinaris* "K-75" (lentil), *Phaseolus mungo* "PV-191" (black gram), *Avena sativa* "HFO-114" (oat), *Trifolium alexandrinum* "Mescavi" (clover), *Brassica juncea* "TLC-1" (Indian mustard) and *Helianthus annuus* "Mhyco MSFH-8" (sunflower) were procured from Punjab Agricultural University, Ludhiana and Indian Agricultural Research Institute, New Delhi.

2.2. Study site and experimental details

The study was carried out in the Northwestern Punjab, India (latitude about 31° N; longitude 77° E and altitude 325 m asl) during the period 1997–1998 in a farmer's fields where trees of *P. deltoides* "Clone G-3" were growing in alleys. Trees were nearly 6 years-old (height 16.20 ± 2.10 m, diameter at breast height 21.60 ± 1.64 cm) with inter- and intra-row distances of 6 and 5 m, respectively (ca. 340 trees/ha). Two adjoining fields each with an area of about 6000 m^2 were selected. In one of the fields, the parent soil (sandy loam) was retained and referred to as S_p, whereas in the other, the top 60 cm of soil was removed and replaced with one collected from a field nearly 100 m away and without *P. deltoides* trees. It was referred to as S_r. In this, the replaced soil was underlined with a polythene sheet to prevent the inflow from the adjoining area. The soil replacement was done in the third week of June, 1997. Nearby, a field without *P. deltoides* (but 50 m away from S_p and S_r fields) was selected for comparison and named the S_c field.

The soil characteristics of the study site were determined and are given in Table I. For this, soil was collected from 0–30 cm depth from ten randomly selected places in the fields with or without *P. deltoides.* The collected samples were pooled and subjected to analysis. For each estimation five replicates were maintained.

In each of these three fields 2 m^2 beds were prepared. Seedbeds were 1.5–2 m away from the trees. In the second week of November (about 20 weeks after replacement of soil), 100 seeds of each crop were sown simultaneously in all the three fields i.e. S_p, S_r and S_c fields. Sowing in three beds each in the respective fields served as replication. Ten days after sowing (DAS) the number of seedlings that emerged were counted. At 30 and 60 days after sowing, 10 plants of each crop randomly selected from each bed were uprooted and their length (from tip of the root to shoot tip) and dry weight were measured. The data on seed germination, seedling length and dry weight was subjected to one way ANOVA followed by Duncan's multiple range test at $p < 0.05$ [4].

Table I. Characteristics of the soil collected from study site (sample size = 5).

Characteristic	Control fields (S_c)	*P. deltoides* fields (S_p)	*P. deltoides* fields (S_r)
Sand %	56.8^b	58.8^{ab}	61.4^a
Silt %	23.6^a	21.1^b	21.5^b
Clay %	19.6^a	19.3^a	17.9^b
pH (1:2, soil:water)	6.98^b	7.30^a	7.04^{ab}
Electrical conductivity (µS)	123.8^b	146.2^a	127.8^b
Organic carbon (%)	0.47^a	0.50^a	0.52^a
Available nitrogen (kg/ha)	168.4^b	188.2^a	176.4^b
Available phosphorus (kg/ha)	53.0^b	58.8^a	55.7^b
Available potassium (kg/ha)	121.54^c	176.4^a	147.9^b
Available iron (mg/kg)	9.14^a	6.86^c	8.15^b
Available zinc (mg/kg)	1.71^c	4.74^a	2.29^b
Available manganese (mg/kg)	29.25^a	23.12^c	26.06^b

Different letters along a row distinguish data that is significantly different at p <0.05 applying DMRT.

2.3. Preparation of leaf leachates and growth studies

Fresh green leaves were collected from the *P. deltoides* sites. Their aqueous leachates were prepared by soaking 25 g of leaves in 100 ml of pure water (conductivity < 0.05 µS, obtained through Millipore RO - Milli Q Water Purification System) for 24 h at 25 °C. These leachates were filtered through a muslin cloth followed by Whatman # 1 filter paper and kept at 4 °C until used. For each set of repetitive experiments, fresh leachates were prepared.

For growth studies, 25 seeds of each test crop were imbibed for 10 h in the leachate solution or pure water (to serve as control) and then equidistantly placed in the 6" dia Petri dishes lined with a Whatman # 1 filter paper and underlined with a thin cotton wad. The Petri dishes were properly moistened with 10 ml leachate solution or pure water. Three such Petri dishes were maintained for each seed type to serve as replicates. All the Petri dishes were kept in a seed germinator maintained at nearly 25 °C temperature and 75% humidity. After one week, the number of seeds germinated and length of the resulting seedlings was measured. The data is represented with respect to control and the treatments and control were analyzed using 2-sample *t*-test at $p < 0.05$ [26].

2.4. Crop performance in litter amended soil

Litter was collected from the floor of *P. deltoides* at the study site. It was powdered and mixed in soil (collected from the vegetation-free area) to get a litter-soil mixture of the concentrations 6.25, 12.5, 25 and 50% (w/w). Similar sets of soil medium were prepared with peat (generally considered to be an inert material) to serve as control. Nearly 500 g of litter or peat amended soil was placed in 4" plastic pots and used for further study taking *T. aestivum* and *L. culinaris* as test crops. These two crops were chosen for the present experiment as these are the major winter crops commonly grown in association with *P. deltoides*. Ten seeds were sown per pot and five pots were maintained for each treatment to serve as replicates. The entire set-up was placed in a seed germinator maintained at 25 ± 3 °C temperature, 75 ± 2% relative humidity and 16 h photoperiod. After two weeks, seedling length and dry weight (oven drying at 70 °C for 24 h) of the germinated seeds were determined.

2.5. Determination of phenolic content

Amount of total phenolics was determined in the freshly prepared aqueous leachates of air-dried fresh leaves (composite of all ages), fresh (yellow) and decaying (brown) litter using Folin-ciocalteu reagent following the method of Swain and Hillis [27] using ferulic acid as standard. These phenolics were also determined in the soil. For this soil samples were collected from the 0–30 cm profile at 2 and 3 m distance from a *P. deltoides* tree. Samples were collected from ten randomly selected places in all the three field conditions and pooled. The phenolic content was determined in the soil – water extracts (1:5, w/v) using Folin-ciocalteu reagent [2]. For each material (soil or leaf or litter) five replicates were maintained. The amount of phenolics has been presented in terms of dry weight as mean ± standard deviation and the different variables were statistically analyzed using one-way ANOVA and the Duncan multiple range test at 5% level of significance.

3. RESULTS AND DISCUSSION

The performance of the winter season crops was poor in association with *P. deltoides* under alley cropping practices compared to sole cropping system (without the tree component). The germination of the test crops was less under *P. deltoides* in both S_p and S_r fields compared to the control field without trees (S_c). However, the performance was better in *P. deltoides* fields where the original parent soil was replaced (S_r) than those in which it was left (S_p) (Tab. II). Among the seven test crops the least germination was observed in the case of *Phaseolus aureus* and *Avena sativa* and the maximum in *T. alexandrinum* (Tab. II). Likewise, the plant height and biomass at 30 and 60 DAS were significantly reduced in all the test crops under both S_r and S_p conditions compared to S_c. However, in *T. aestivum* and *L. culinaris* at 30 DAS the biomass did not show a significant change in S_r fields compared to either S_p or S_c fields, respectively (Tab. III). By and large, the reduction in both plant height and biomass ranged from 10 to 30%. Maximum decrease in plant height and biomass was observed in the *B. juncea* plant followed by *P. aureus* whereas very little (but significant) effect was observed in the case of *T. alexandrinum* (Tab. III). In all crops, however, the lowest value of germination, plant height and biomass were measured in S_p fields (Tabs. II, III).

Table II. Percent germination of test crop plants in different fields (sample size = 9).

Crop	Control fields (S_c)	*P. deltoides* fields (S_r)	*P. deltoides* fields (S_p)
Triticum aestivum	89±4.4[a]	86±2.1[a]	78±2.5[b]
Lens culinaris	92±3.4[a]	85±2.2[b]	77±2.4[c]
Phaseolus mungo	97±2.6[a]	90±1.4[b]	66±4.6[c]
Avena sativa	84±1.8[a]	75±2.9[b]	64±3.4[c]
Trifolium alexandrinum	96±3.2[a]	91±1.7[b]	85±2.3[c]
Brassica juncea	94±2.8[a]	88±1.5[b]	76±2.9[c]
Helianthus annuus	86±2.6[a]	79±1.4[b]	71±2.8[c]

Different letters along a row distinguish data that is significantly different at $p < 0.05$ applying DMRT. ± represents standard deviation.

Table III. Height and biomass at 30 and 60 DAS in different fields and for different crop species (sample size = 9).

Crop species	Type of field	Height (cm)		Biomass (g)	
		30 days	60 days	30 days	60 days
Triticum aestivum	S_c	17.60[a]	53.75[a]	0.30[a]	1.29[a]
	S_p	12.70[c]	35.00[c]	0.15[b]	0.61[c]
	S_r	14.13[b]	40.38[b]	0.16[b]	0.70[b]
Lens culinaris	S_c	10.34[a]	32.13[a]	0.09[a]	1.07[a]
	S_p	8.64[c]	16.70[c]	0.042[b]	0.18[c]
	S_r	9.38[b]	27.76[b]	0.088[a]	0.49[b]
Phaseolus mungo	S_c	36.20[a]	71.20[a]	1.55[a]	3.99[a]
	S_p	22.10[c]	34.37[c]	0.90[c]	2.04[c]
	S_r	24.53[b]	46.89[b]	0.98[b]	2.29[b]
Avena sativa	S_c	14.94[a]	45.60[a]	0.37[a]	1.89[a]
	S_p	11.00[c]	25.75[c]	0.10[c]	0.58[c]
	S_r	11.53[b]	33.00[b]	0.19[b]	1.00[b]
Trifolium alexandrinum	S_c	11.66[a]	37.92[a]	0.04[a]	0.54[a]
	S_p	10.10[c]	24.86[c]	0.02[c]	0.15[c]
	S_r	10.64[b]	32.73[b]	0.034[b]	0.25[b]
Brassica juncea	S_c	15.80[a]	74.75[a]	0.42[a]	2.51[a]
	S_p	4.87[c]	29.12[c]	0.09[c]	0.47[c]
	S_r	5.90[b]	33.50[b]	0.13[b]	0.73[b]
Helianthus annuus	S_c	24.50[a]	70.60[a]	2.09[a]	8.86[a]
	S_p	13.90[c]	36.50[c]	0.58[c]	2.08[c]
	S_r	18.50[b]	48.70[b]	1.06[b]	3.62[b]

Different letters along a column distinguish data that is significantly different at $p < 0.05$ applying DMRT.

In the present study, the aqueous leachates of *P. deltoides* leaves markedly inhibited the germination (except *A. sativa* and *T. alexandrinum*) and growth of all the test crops (Tab. IV). Among the seven test crops, maximum inhibitory effect was observed in the case of *P. mungo* where none of the seeds could germinate, whereas in the case of *L. culinaris* only about 28% of seeds germinated in response to aqueous leachates. Likewise, the seedling length of all the test crops was significantly reduced in response to aqueous leachates of *P. deltoides* leaves and the maximum effect was in *T. aestivum* followed by *L. culinaris* (Tab. IV).

Not only the fresh leaf leachates, even the litter amended in the soil was observed to have a negative effect on seedling length and dry weight of *L. culinaris* and *T. aestivum*, whereas, in the peat amended soil, a growth promotory effect was observed (Fig. 1). The seedling length and weight of both *T. aestivum* and *L. culinaris* decreased with the increasing amount of litter amended in the soil. Even at the lowest concentration of litter amended soil (6.25%, w/w), a significant reduction in the seedling length of both the crops was observed (Fig. 1). The inhibitory effect of the leaves and decaying litter of *P. deltoides* are due to the presence of allelochemicals or phytotoxins which are released upon leaching and decomposition. A number of reports available in the literature indicate the inhibitory effects of the tree litter on the associated crops and herbs [1, 3, 7, 18, 21, 23]. The decaying litter and residues from the trees, in general, are found to be rich in phytotoxic phenolics that interfere with the growth of associated plants [6, 7, 11, 14–16, 23]. In the present study also, the fresh leaves, fresh and decaying litter and the soil from the *P. deltoides* fields was observed to have an appreciable amount of phenolics (Tab. V). Fresh litter comprising of yellow senescent leaves was found to contain more phenolics compared to fresh green leaves and decaying brown leaves. This could be due to synthesis of more phenolics in the senescent leaves which are under stress; as the production of allelochemicals is enhanced under stress conditions [5]. The amount of the phenolics was significantly more in the S_p fields compared to S_r fields and least in S_c fields (Tab. V). Such a trend of phenolics content was in accordance with the observed inhibitory effect that was more pronounced in S_p fields (where parent soil was retained) than S_r fields (where parent soil was replaced). The amount of phenolics in the S_p fields was found to be increased nearly two-fold. This could be explained by the presence of already accumulated phytotoxins as well as their continuous influx from the tree to the soil in the S_p fields which add to the existing pool of the phytotoxins in the original soil. On the other hand, in S_r fields there is only fresh influx of the allelochemicals from the aerial parts and fallen leaves (as is evident from Tab. V). Though this increase in the phenolics in the S_r fields is three-fold compared to the two-fold increase in S_p fields, yet the total amount added after the experiment is nearly the same in both S_r and S_p fields (Tab. V). These phenolics upon their release through decomposition aided by soil microbes could be responsible for the observed poor crop performance in association with *P. deltoides*. It seems plausible in the light of several reports, which indicate the allelopathic nature of *P. deltoides* on understorey vegetation/adjoining plants [9, 10, 24, 25]. Therefore, on the basis of the observations made in the present study the reduction in the germination and growth of the crops grown in association with

Table IV. Germination and seedling length of test crops in response to aqueous leachates of *P. deltoides* leaves.

Crop species	Germination (% of control)	Seedling length (% of control)
Triticum aestivum	46.9 ± 4.8	22.3 ± 1.6
Lens culinaris	27.7 ± 3.6	32.6 ± 2.7
Phaseolus mungo	0	–
Avena sativa	94.7 ± 1.8^{ns}	70.7 ± 4.6
Trifolium alexandrinum	95.2 ± 2.7^{ns}	69.4 ± 6.3
Brassica juncea	47.4 ± 1.5	41.7 ± 2.4
Helianthus annuus	52.9 ± 2.9	48.3 ± 3.8

ns represents insignificant difference between the control and the treatment at $p < 0.05$ applying two sample *t*-test.

Table V. Amount of water-soluble phenolics in the leaves and soil from *P. deltoides* fields (sample size = 5).

Part used	Phenolic content (mg/100 g DW)
Fresh leaves	63.30 ± 4.25
Fresh litter	132.54 ± 1.87
Decaying litter	60.60 ± 2.79
Soil from S_p fields	
Before experiment	14.21 ± 1.85*
After experiment	29.33 ± 3.06
Soil from S_r fields	
Before experiment	6.79 ± 0.83*
After experiment	19.02 ± 1.48
Soil from S_c fields	
Before experiment	6.19 ± 0.68^{ns}
After experiment	6.56 ± 0.72^{ns}

Before experiment: October, 1997; After experiment: March 1998; ± represents standard deviation; ns and * represent insignificant and significant difference, respectively, at $p < 0.05$ between the amount of phenolics before and after experiment for a particular field type.

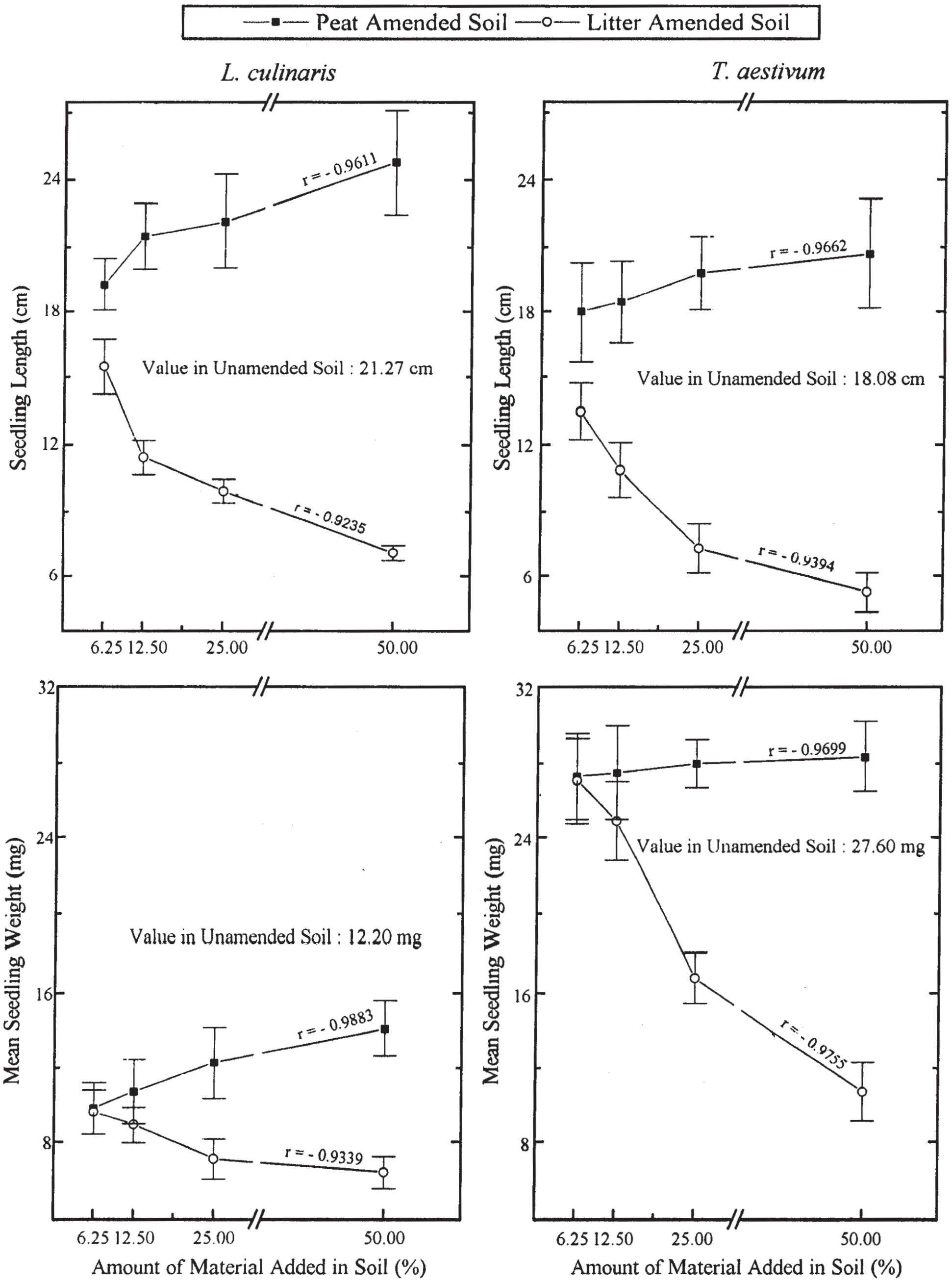

Figure 1. Growth performance of *L. culinaris* and *T. aestivum* in the litter or peat amended soil. *r* value along each curve represents correlation coefficient between different concentration and the respective parameter. Vertical bars represent the standard deviation (sample size = 10).

P. deltoides could be attributed to the phenolics released from the tree. Though, at the same time the role of other components such as terpenes and factors like competition for sharing of growth resources, involvement of microbes, role of soil macrofauna, etc. cannot be ignored.

The better crop performance in the fields without *P. deltoides* was perhaps due to the lack of interference from the trees. Sanchez [20] reported that growing of crops concomitantly with the trees has limited applicability because of the presence of more competitive forces in such systems e.g. competition between trees and crops for moisture, nutrients and light. Rao et al. [17] have emphasized that in the tropics, particularly under simultaneous agroforestry systems, allelopathy is one of the major determining factors in tree-crop-soil interactions and plays an important role in influencing both the negative effects and the positive benefits in the annual cropping system. The reasons for the observed reduction in the present study may, therefore, be explored in terms of interference (competition and/or allelopathy) between tree and crops and shading effect. Since the soil nutrients in the study site with or without trees were nearly the same or even better in *P. deltoides* fields (Tab. I), the reduced growth performance could not be entirely attributed to nutrient shortage. Even if enough nutrients are present it is likely that they are not equally available for *Populus* trees and crops due to the difference in the root system length (and analyses were made on a large sample; from 0–30 cm depth). Moreover, the moisture was also not limiting as the study was conducted under irrigated conditions; though some competition may be there between crop roots and the finer roots of *P. deltoides* (mainly confined to 0–30 cm soil profile). The shading effect was negligible owing to the shedding of leaves by *P. deltoides* in winter. On the other hand, the fallen leaves of *P. deltoides* which form a matrix on the floor may release phytotoxins through leaching or decomposition since the leaves and decaying litter of *P. deltoides* has been reported to be phytotoxic in nature [8, 10]. During the study time nearly 3470 kg/ha of litter fall was recorded which is quite a significant amount. Therefore, the possibility of allelopathic interference of the *P. deltoides* trees with crops could be the reason for the observed poor crop performance.

4. CONCLUSION

From the present study, it could be concluded that crops perform poorly in association with *P. deltoides*. Different test crops showed differential response. Some crops like *B. campestris* and *P. mungo* were found to be more sensitive whereas others like *A. sativa* were less sensitive. The leaves and litter of *P. deltoides* was found to be rich in phytotoxic phenolics. However, based on the data presented in the study, the observed reductions could at least partially be ascribed to allelopathic interference due to the decaying leaves and litter of the tree which accumulate on the ground and release phytotoxic phenolics upon leaching and decomposition.

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