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Article

Allelopathic Effects of Rose Wood, Guava, Eucalyptus, Sacred Fig and Jaman Leaf Litter on Growth and Yield of Wheat (*Triticum aestivum* L.) in a Wheat-Based Agroforestry System

*Efeitos Alelopáticos da Serapilheira de Pau-Rosa, Goiabeira, Eucalipto, Figueira-Sagrada e Jamelão no Crescimento e Rendimento de Trigo (**Triticum aestivum** L.) em Um Sistema Agroflorestal Baseado no Cultivo de Trigo*

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ABSTRACT - Selection of tree species under agroforestry systems is crucial to sustain the productivity of a crop. In present study, allelopathic effects of the leaf litters of 5 trees named Rose wood (*Dalbergia sissoo*), Guava (*Pisidium guajava*), Eucalyptus (*Eucalyptus camaldulensis*), Sacred fig (*Ficus religiosa*) and Jaman (*Syzygium cumini*) species on wheat growth and yield was examined. Leaf litter of each tress species was mixed in soil with two doses @ 100 and 200 g of leaves of each species per pot. Higher shoot length, shoot dry weight, number of spikelets per spike and biological yield were recorded in 200 g sun dried Jaman (*Syzygium cumini*) leaves. Total number of tillers per plant and number of ears per plant were higher under the application of *Eucalyptus camaldulensis* leaves (200 g sun dried) as compared to other treatments. Spike length, grain yield per pot, number of grains per pot and harvest index were maximum in 200 g sun-dried Sacred fig (*Ficu sreligiosa*) leaves. Majority of the parameters were promoted at lower doses of leaves per pot, however, at higher doses they started inhibiting the growth and grain yield of wheat.

Keywords: allelopathy, agroforestry, wheat growth, crop production.

*RESUMO - A seleção de espécies arbóreas em sistemas agroflorestais é essencial para sustentar a produtividade da cultura. No presente estudo, foram investigados os efeitos alelopáticos da serapilheira das folhas de cinco árvores – pau-rosa (**Dalbergia sissoo**), goiabeira (**Pisidium guajava**), eucalipto (**Eucalyptus camaldulensis**), figueira-sagrada (**Ficus religiosa**) e jamelão (**Syzygium cumini**) – no crescimento e rendimento do trigo. A serapilheira de cada espécie foi misturada no solo com duas doses de 100 e 200 g de folhas de cada espécie por vaso. Foram observados valores maiores para comprimento da parte aérea, peso seco da parte aérea, número de espiguetas por espiga e rendimento biológico em 200 g de folhas de jamelão (**Syzygium cumini**) secas ao sol. O número total de perfilhos por planta e o número de espigas por planta foram maiores na aplicação de folhas de **Eucalyptus camaldulensis** (200 g, secas ao sol), em comparação com os demais tratamentos. O comprimento de espiga, o rendimento de grãos por vaso, o número de grãos por vaso e o índice de colheita obtiveram valores máximos em 200 g de folhas de figueira-sagrada (**Ficus religiosa**) secas ao sol. A maioria dos parâmetros mostrou aumento com doses mais baixas de folhas por vaso; no entanto, em doses mais elevadas, ocorreu inibição do crescimento e da produção de grãos de trigo.*

Palavras-chave: alelopatia, agrossivicultura, crescimento do trigo, produção agrícola.

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INTRODUCTION

Wheat (*Triticum aestivum*) is the first domesticated food crop and the basic foodstuff of the common people in many regions of the world. Being the most important staple food of Pakistan, it is grown on more land area than any other commercial crop. Its contribution to value addition in agriculture is 10.0 percent and share to GDP is 2.1 percent (Pakistan, 2015). Wheat is cultivated in an area of 9,180 thousand hectares, producing 25.478 million tons with an average production of 2.775 tons per hectare (Pakistan, 2015). Population increasing in wheat-consuming countries required more wheat for fulfill the requirement of the population for this purpose adaptation of approaches are necessary for sustainable wheat production. Enhancement of both crop superiority and yield is an urgent task. Optimally, yield improvement must be achieved through agronomic approaches that are environmentally safe and sound (Olofsdotter et al., 1997).

In agroforestry, the importance of multipurpose tree species cannot be overlooked as they provide food, fodder, fuel wood and social security to the growers. Some species improve the soil but at the same time some species may cause adverse effects on a long-term basis (Gill et al., 1992; Mughal, 2000). Plant canopy plays an important role in acquisition of nutrients, water as well as light and air in accordance with different species. Plant canopy suppresses the other growing plants because of its shading effect, hence it affects other plants either positively or negatively. The component plant species in an agroforestry system depends on the same reserve of growth resources such as light, water and nutrients and hence there will be influence of one component of a system on the performance of the other components as well as of the system as a whole. These are referred to as tree-crop interactions. These interactions may be positive or negative. The balance between these positive and negative effects determines the overall effects of the interactions in a given agroforestry combination (Bhatt et al., 1993; Huang et al., 1997; Basavaraju et al., 2000; and Jaenicke et al., 2002).

Many tree species have been reported as beneficial as well as harmful for different crops. Selective action of tree allelochemicals on crops and other plants has also been reported; for example, *Leucaena leucocephala*, the marvel tree promoted for revegetation, soil and water protection and animal improvements in India. *Leucaena* species have also been shown to decrease the yield of wheat but enhance the yield of rice. Foliar and leaf litter leachates of *Eucalyptus* species are more toxic than bark leachates to some food crops (Rizvi et al., 1999).

Trees and agronomic crops interact in many ways, e.g., allelopathic interactions, competition and effect on physico-chemical properties of the soils. During the autumn, many of the trees shed their leaves. These leaves can affect the grown crop in many ways. Because these species co-exist along with agricultural crops, their allelopathic compatibility may be essential to conclude the accomplishment of an agroforestry system. Therefore, it is desirable to conduct further research in this direction so that agroforestry species with any allelopathic effects on the companion crops may be promoted for agroforestry programs. As agroforestry species remain a part of the agroecosystem for a longer period, and most of them produce a huge amount of leaves and litter, their allelochemicals may play a significant role in promoting an eco-friendly pest management policy. In addition to these generally studied aspects of allelopathy, some reasonably newer aspects of research have been recognized, such as estimate of qualitative yield of agroforestry systems, selective performance of allelochemicals, effect on soil quality, and the role of tree allelochemicals in animal and human nourishment. If given enough consideration, allelopathy could play an essential role in preservation of extremely endangered surroundings, biodiversity and natural reserve bases; moreover, it can make agriculture more sustainable by broadening the scope of agroforestry (Kruse et al., 2000). Other effects of litter fall may be the addition of organic matter. This may play a positive role by releasing different essential nutrients and improving soil physico-chemical properties (Arriaga and Lowery, 2003; Hadrian et al., 2006; Nyiraneza, 2009).

Wheat crop is also grown under agroforestry systems; Sheikh and Haq (1986) reported that wheat yield was depressed when grown under trees, but total yield of wheat from a tree-associated plot was higher than that of the control plot. Trees (*Dalbergia sissoo, Tamarix aphylla* and *Populus deltoides)* were not different in their allelopathic effect on crop yield. The farmer was able to compensate crop loss through the sale of trees at fairly good prices. There was a depressing effect of poplar rows on the yield of sugarcane crop up to 10 m away from the trees. The ground vegetation under its canopy indicates that it has some allelopathic potential which might have been caused either by fallen leaves (through decomposition of leaves) or plant leachates or root exudates. Consequently, the release of allelochemicals (organic substances) into the soil inhibits seed germination and establishment of agricultural crops and vegetation.

The selected trees during the present study have shown different effects on the field crops. Alebachew et al. (2015) reported that there was a significant reduction in crop biomass and yield when maize (*Zea mays*), finger millet (*Eleusine coracana*) and broomcorn millet (*Panicum miliaceum*) were grown adjacent to Eucalyptus trees. They affirmed that the suppressive effect of Eucalyptus was higher where plant stands were close to Eucalyptus, and its effect decreased as distance was increased in all the three crops. Thus, it expresses the allelopathic potential of Eucalyptus and other trees in agroforestry based cropping system. Additionally, Hussain et al. (1994) reported that the adverse effect of leaf extracts of *Syzygium cumini* on root growth and nutrient uptake resulted in reduced shoot growth. They further reported that effective microorganism (EM) application reduced the adverse effect and enhanced shoot growth significantly, through a better root system as a result of the decomposition of organic matter, which promotes the growth of crop plants. Keeping in view different interactions of the agroforestry systems, the present research was conducted in order to: (1) demonstrate the effects of the leaf litter of some tree species on wheat crop, (2) select suitable tree species that have a positive effect on wheat crop and are fit for an agroforestry system.

MATERIALS AND METHODS

A pot experiment was conducted at the College of Agriculture, Dera Ghazi Khan, to find out the effects of leaf litter of 5 trees named Rose wood, *(Dalbergia sissoo),* Guava (*Psidium guajava*), Eucalyptus *(Eucalyptus camaldulensis),* Sacred fig *(Ficus religiosa)* and Jaman *(Syzygium cumini)* on wheat crops. Large earthen pots (42 cm in diameter, 36 cm in depth) had soil of 26 kg in each pot. Sun dried leaves of Rose wood, Guava, Eucalyptus, Sacred fig, and Jaman @ 100 and 200 g pot^{-1} were thoroughly mixed with soil. Wheat nursery of cultivar Mairaj-2008 was raised by sowing seeds in plastic trays and then transplanted to the pots at the rate of 4 seedlings per pot after two weeks. Tape water was used to irrigate the plants and moisture contents were maintained at 95% FC throughout the experiment. The experiment was laid out in a Completely Randomized Design (CRD) with 4 replications. Four grams each of nitrogen and P_2O_5 were applied to each pot. Urea and Diamonium phosphate (DAP) were used as sources of fertilizers. All agronomic practices other than the treatments were kept identical.

Treatments

T_1 : Control

T_2 : *Dalbergia sissoo* leaves @ 100 g pot^{-1}

T_3 : *Dalbergia sissoo* leaves @ 200 g pot^{-1}

T_4 : *Psidium guajava* leaves @ 100 g pot^{-1}

T_5 : *Psidium guajava* leaves @ 200 g pot^{-1}

T_6 : *Eucalyptus camaldulensis* leaves @ 100 g pot^{-1}

T_7 : *Eucalyptus camaldulensis* leaves @ 200 g pot^{-1}

T_8 : *Ficus religiosa* leaves @ 100 g pot^{-1}

T_9 : *Ficus religiosa* leaves @ 200 g pot^{-1}

T_{10} : *Syzygium cumini* leaves @ 100 g pot^{-1}

T_{11} : *Syzygium cumini* leaves @ 200 g pot^{-1}

Observations and statistical analysis

Shoot length of every plant from each pot of wheat was measured for maturity in centimeter with a measuring tape and then averages were computed. The shoots of wheat were cut at their base, air-dried and their dry weights were measured with an electrical balance. Total number of tillers and ears per plant were counted five times in each pot manually and their averages were recorded. Similarly, spike length of wheat was measured 5 times with the help of a measuring tape in centimeters and then the averages were calculated on a per pot basis. Meanwhile, the number of spikelet per spike of wheat was calculated and their average was recorded on a pot basis. Number of grains from each of the spikes was counted 5 times manually and their average was calculated. 100 grains were randomly taken from the seed lot of every pot to calculate the average weight of 100 grains. For determination of biological yield, weight of harvested sun-dried plants (shoot and spike) was recorded on a pot basis. After harvesting the plant at maturity, spikes were separated, sun-dried, threshed manually from each pot; then, the grains were cleaned and yield was recorded.

The experiment was arranged using a completely randomized design with four replications. All the analyses were duplicated, and the average value from each duplicate was used for statistical analysis. Data were analyzed by analysis of variance techniques with the Statistix 8.1 (Analytical Software, Tallahassee, FL, USA) software. The mean differences between treatments were separated using the least significance difference (LSD) test at 0.05 probability level. Graphical presentation was made using the Sigma Plot 10.0 software (Systat Software Inc., San Jose, CA, USA).

RESULTS AND DISCUSSION

Effect of leaf litter of different tree species on shoot length of wheat

Wheat growth and related traits were significantly influenced by the application of leaf litter from different tree species (Table 1). Maximum shoot length (60.01 cm) was recorded in T_{11} (wheat with 200 g sun-dried *Syzygium cumini* leaves) that showed stimulatory effect as compared to control, and it was statistically similar to T_8 (Wheat with 100 g sun-dried *Ficus religiosa* leaves), T_5 (Wheat with 200 g sun-dried *Psidium guajava* leaves), T_6 (Wheat with 100 g sun-dried *Eucalyptus camaldulensis* leaves) and T_7 (Wheat with 200 g sun-dried *Eucalyptus camaldulensis* leaves). *Dalbergia sissoo* leaves have a comparatively lower promotive effect as compared to other tree species. The reason for variation in effects of Eucalyptus and Rose wood might be due to the presence of higher allelopathic contents such as benzoic, cinnamic and phenolic acids, which have the potential to inhibit neighboring plants either positively or negatively depending on their concentrations. Higher doses of leaves pot^{-1} (200 g leaves pot^{-1}) of *Dalbergia sissoo, Psidium guajava,* and *Eucalyptus camaldulensis* were insignificant as compared to their lower doses of leaves (100 g leaves pot^{-1}); however, *Ficus religiosa* and *Syzygium cumini* produced higher shoot length by increasing the dose of leaves pot^{-1} (Table 2).

These results are in line with those of Rashid and Hafeez (1991), who found that wheat yield was reduced when grown adjacent to Rose wood (*Dilbergia sissoo*), with respect to distance from

Table 1 - Summary of ANOVA showing the allopathic effects of leaf litters of different tree species on wheat growth and yield

SOV	Shoot length (cm)	Shoot dry weight (g)	Total no. tillers per plant	Number of ears per plant	Spike length	Number of spikelets spike^{-1}	Number of grains spike^{-1}	Number of grains pot^{-1}	100-grain weight (g)	Biological yield (g pot^{-1})	Grain yield (g pot^{-1})	Harvest index (%)
Treatment	267.11**	253.13**	46.59**	19.06**	13.73**	45.48**	584.74**	354652.20**	0.39**	4050.10**	565.16**	1177.84**
Error	31.42	2.31	2.78	2.65	5.65	6.03	9.52	21469.59	0.08	36.99	12.84	48.62

SOV= Source of variation; ** and * denote significance at the 0.01 and 0.05 probability levels, respectively. ns: non-significant.

Table 2 - Allelopathic effects of leaf litter application of different tree species on wheat growth and yield-related traits

Treatment	Shoot length (cm)	Total no. tillers per plant	Number of ears per plant	Spike length	Number of spikelets spike^{-1}	Number of grains spike^{-1}	Number of grains pot^{-1}
T1	50.99 f	4.14 e	3.08 d	8.56 d	11.44 f	32.20 e	408.00 g
T2	55.13 e	7.42 b	4.75 c	10.45 abc	14.58 bc	32.61 e	618.33 e
T3	54.71 e	6.92 cd	4.67 c	9.98 bc	13.55 e	39.85 a	742.00 a
T4	57.62 bcd	6.92 cd	4.67 c	9.78 c	13.78 de	37.93 b	704.33 abc
T5	58.83 abc	7.25 bc	4.75 c	10.32 abc	13.75 de	36.51 c	690.67 bc
T6	58.62 abc	7.42 b	5.58 ab	10.19 abc	14.39 cd	29.91 f	668.00 cd
T7	58.50 abc	8.20 a	5.75 a	10.42 abc	14.80 abc	26.62 g	577.00 f
T8	59.07 ab	6.16 e	4.83 c	9.86 c	14.17 cde	35.61 d	678.33 c
T9	56.83 d	6.75 d	5.25 b	10.69 a	15.17 ab	35.30 d	728.00 a
T10	57.29 cd	5.82 e	4.58 c	10.09 abc	14.43 cd	35.25 d	637.00 de
T11	60.01 a	7.33 bc	4.75 c	10.61 ab	15.41 a	37.21 bc	707.67 abc
LSD value	1.40	0.41	0.40	0.59	0.61	0.77	36.69

Different lowercase letters denote statistical differences between treatments of a cultivar at the 5% probability level according to the Least Significance test. Values following the mean data are SE (n=4). T1=control; T2= *Dalbergia sissoo* leaves @ 100 g pot^{-1}; T3= *Dalbergia sissoo* leaves @ 200 g pot^{-1}; T4= *Psidium guajava* leaves @ 100 g pot^{-1}; T5= *Psidium guajava* leaves @ 200 g pot^{-1}; T6= *Eucalyptus camaldulensis* leaves @ 100 g pot^{-1}; T7= *Eucalyptus camaldulensis* leaves @ 200 g pot^{-1}; T8= *Ficus religiosa* leaves @ 100 g pot^{-1}; T9= *Ficus religiosa* leaves @ 200 g pot^{-1}; T10= *Syzygium cumini* leaves @ 100 g pot^{-1}; T11= *Syzygium cumini* leaves @ 200 g pot^{-1}.

the crop. Similarly, Singh et al. (1992) concluded that aqueous extracts of sun-dried leaf litter of *Eucalyptus citirodora* had adverse effect on wheat growth, and the Eucalyptus tree belt had inhibitory effect on wheat. Moreover, Patil et al. (2003) observed the inhibitory effect of eucalyptus (*Eucalyptus tereticornis*) on wheat germination percentage, shoot and root length, and shoot and root dry weight per plant. These results suggest that these trees contain several allelochemicals such as cinnamic and phenolic acids, which have the ability to suppress or stimulate the target plant species dependingon their concentration.

Effect of leaf litter on total number of ears per plant

Total number of ears per plant is an important parameter which enhances the productivity of wheat crops. The higher the number of tillers per plant, the higher the crop yield will be. The data in Table 1 showed significant effect of leaf litter of different tree species on number of ears per plant. The maximum number of ears per plant (8.20) was recorded in T_7 (wheat with 200 g sun-dried *Eucalyptus camaldulensis* leaves) followed by T_2 (wheat with 100 g sun-dried *Dalbergia sissoo* leaves), T_6 (wheat with 100 g sun-dried *Eucalyptus camaldulensis* leaves) and T_{11} (wheat with 200 g sun-dried *Syzygium cumini* leaves), which were statistically at par with each other, while the minimum number of ears per plant (4.14), (5.82) and (6.16) was recorded in T_1 (control) and T_{10} (wheat with 100 g sun-dried *Syzygium cumini* leaves) and T_8 (wheat with 100 g sun-dried *Ficus religiosa* leaves), respectively. Higher leaf doses (200 g leaves pot^{-1}) of *Dalbergia sissoo, Eucalyptus camaldulensis, Ficus religiosa* and *Syzygium cumini* produced a higher number of tillers as compared to their lower doses (100 g leaves pot^{-1}). However, *Psidium guajava* showed no response by increasing its dose of leaves pot^{-1} (Table 2). Variation as a result of total number of ears per plant in grain yield was 19.42% and the relationship was positive (Figure 1).

These results are in contrast to those of Patel et al. (2002), who reported that eucalyptus trees reduced germination, growth and yield of wheat crops. They further stated that aqueous extracts of different concentrations of *Eucalyptus camaldulensis* significantly affected and reduced dry weight, germination and growth of wheat seedlings compared with the control. The adverse effects gradually increased as concentration increased. Aqueous extracts of tree species can be prepared by using different parts such as leaves, branches, flowers and root as well. Most of the secondary compounds are water soluble and have an inhibitory or a stimulatory effect, and water serves as the carrier and medium to express allelopathy (Farooq et al., 2011). Khan et al. (1999) reported that the aqueous extract from eucalyptus leaves reduced the germination and

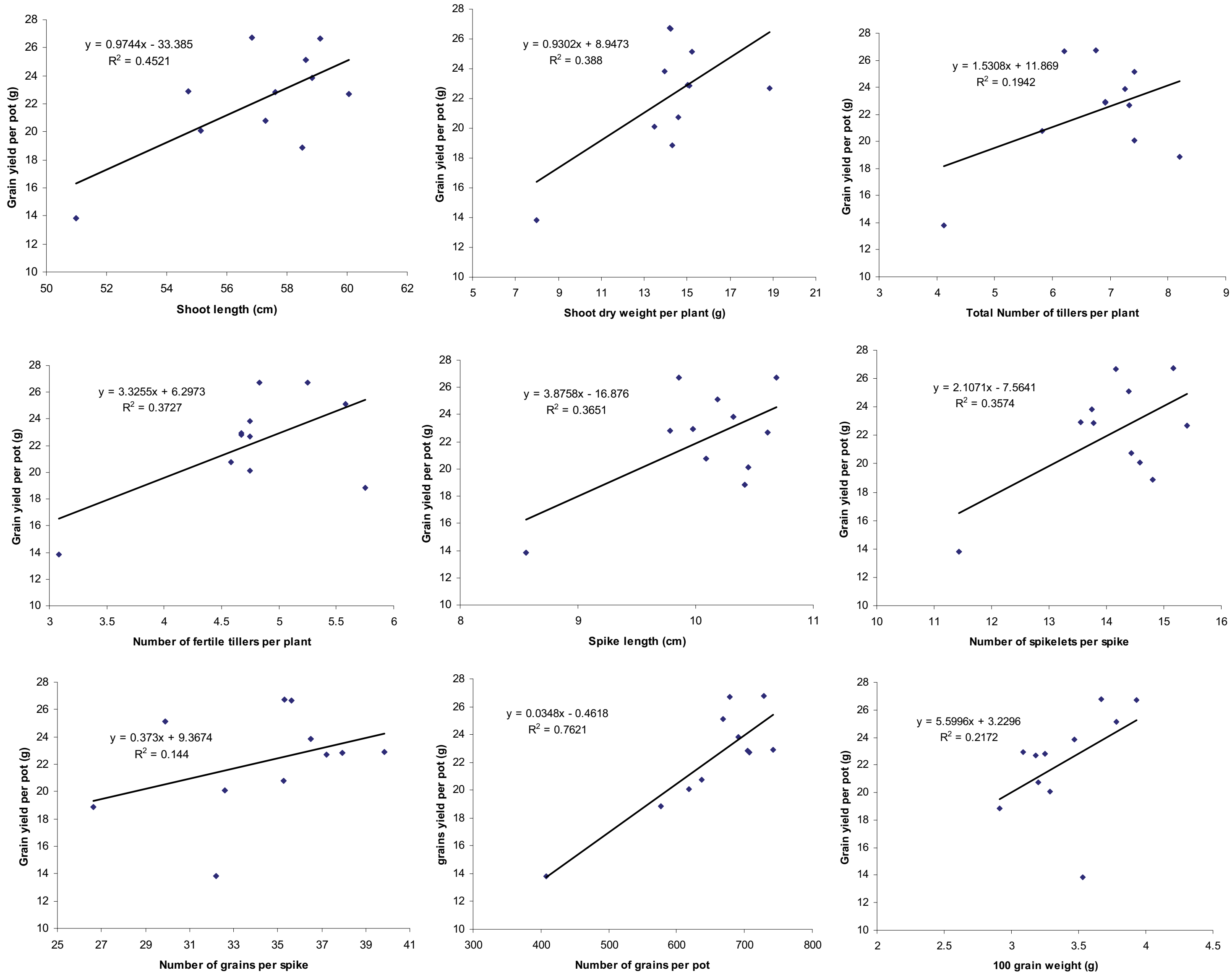

Figure 1 **-** Correlation analysis between wheat yield and its different yield-related traits.

seedling growth in a number of crops such as sorghum, cotton, sunflower and mung bean. The probable reason for inhibition was uptake of allelochemicals in water by the seedlings and reduction in other physiological processes of wheat in the present study.

Effect of leaf litter on number of ears per plant

The leaves of all the tree species were affected significantly, as they produced a higher number of ears per plant as compared to the control (Table 1). The maximum number of ears per plant (5.75) was recorded in T_7 (wheat with 200 g sun-dried *Eucalyptus camaldulensis* leaves) and was on par with T_6 (wheat with 100 g sun-dried *Eucalyptus camaldulensis* leaves) followed by T_9 (wheat with 200 g sun-dried *Ficus religiosa* leaves), while T_2 (wheat with 100 g sun-dried *Dalbergia sissoo* leaves), T_3 (wheat with 200 g sun-dried *Dalbergia sissoo* leaves), T_4 (wheat with 100 g sun-dried *Psidium guajava* leaves), T_5 (wheat with 200 g sun-dried *Psidium guajava* leaves), T_8 (wheat with 100 g sun-dried *Ficus religiosa* leaves), T_{10} (wheat with 100 g sun-dried *Syzygium cumini* leaves) and T_{11} (wheat with 200 g sun-dried *Syzygium cumini* leaves) produced a higher number of ears per plant as compared to the control but less than *Eucalyptus camaldulensis* and *Ficus religiosa* at a higher dose of leaves. The minimum number of ears per plant (3.08) was recorded in T_1 (control). Higher doses (200 g leaves pot^{-1}) of all the tree species except *Ficus religiosa* have an insignificant effect as compared to lower doses (100 g leaves pot^{-1}). Variation as a result of number of ears per plant in grain yield was 37.27% and the relationship was positive (Figure 1). These results are in contrast to those of Alam and Islam (2002), who reported that the *Eucalyptus camaldulensis* plant produces chemicals which interfere with wheat crop and affect seed germination and seedling growth. The positive effect might be due to the organic matter added through the leaves in the pots (Ghafoor et al., 2008).

Effect of leaf litter on spike length (cm)

The leaves of all tree species significantly affected spike length as compared to the control (Table 1). Maximum spike length (10.69) was recorded in T_9 (wheat with 200 g sun-dried *Ficus religiosa* leaves) and it is at par with T_{11} (Wheat with 200 g sun-dried *Syzygium cumini* leaves), T_2 (wheat with 100 g sun-dried *Dalbergia sissoo* leaves), T_5 (wheat with 200 g sun-dried *Psidium guajava* leaves), T_6 (wheat with 100 g sun-dried *Eucalyptus camaldulensis* leaves), T_7 (wheat with 200 g sun-dried *Eucalyptus camaldulensis* leaves), T_{10} (wheat with 100 g sun-dried *Syzygium cumini* leaves). Minimum spike length (8.56) was recorded in T_1 (control). Higher doses (200 g leaves pot^{-1}) of all the tree species except *Ficus religiosa* have an insignificant effect as compared to lower doses (100 g leaves pot^{-1}). Variation as a result of spike length in grain yield was 36.51% and the relationship was positive (Figure 1). The promotive effect might be due to the organic matter added through the leaves in pots (Ghafoor et al., 2008) while Alam and Islam (2002) reported the inhibitory effect of *Eucalyptus camaldulensis* and stated that the plant produces chemicals which interfere with wheat crop and affect seed germination and seedling growth.

Effect of leaf litter on number of spikelets spike^{-1}

Yield potential of wheat crop depends upon its spike length and number of spikelets per spike as more number of grains per spike. Number of spikelets per spike is highly dependable on spike length as it has vital role in the production potential of wheat crop. The number of spikelets per spike is highly dependable on spike length as it has a vital role in the production potential of wheat crops. The leaf litter of all 5 tree species significantly enhanced the number of spikelets spike^{-1} (Table 1). Maximum number of spikelets spike^{-1} (15.41) was recorded in T_{11} (wheat with 200 g sun-dried *Syzygium cumini* leaves) and is at par with T_9 (wheat with 200 g sun-dried *Ficus religiosa* leaves) and T_7 (wheat with 200 g sun-dried *Eucalyptus camaldulensis* leaves) followed by T_2 (wheat with 100 g sun-dried *Dalbergia sissoo* leaves). Minimum number of spikelets spike^{-1} was recorded in T_1 (control). Variation as a result of number of spikelets spike^{-1} in grain yield was 35.74% and the relationship was positive (Figure 1). Higher doses of leaves (200 g leaves pot^{-1}) of *Dalbergia sissoo, Ficus religiosa* and *Syzygium cumini* produced a higher number of spikelets spike^{-1} as compared to lower doses (100 g leaves pot^{-1}) (Table 2). The positive effect of *Syzygium cumini* on number of spikelets spike^{-1} is supported by Hussain et al. (1994); growth and nutrient uptake is enhanced because of organic matter decomposition. The negative effect at higher concentrations might be due to the increase in allelochemical concentration after decomposition (Patel et al., 2002). However, Geleto et al. (1995) reported that grain yield is closely related to number of spikes per unit area.

Effect of leaf litter on number of grains spike^{-1}

Productivity potential of any crop depends on the number of grains per spike, which plays an important role in the economic yield of wheat. Data presented in Table 1 showed that all 5 tree species significantly affected the number of grains spike^{-1}. Maximum number of grains spike^{-1} (39.85) was recorded in T_3 (wheat with 200 g sun-dried *Dalbergia sissoo* leaves) followed by T_4 (wheat with 100 g sun-dried *Psidium guajava* leaves) and T_{11} (wheat with 200 g sun-dried *Syzygium cumini* leaves). Variation as a result of number of grains spike^{-1} in grain yield was 14.4% and the relationship was positive too (Figure 1). *Eucalyptus camaldulensis* leaves inhibited the number of grains spike^{-1} as compared to the control; *Dalbergia sissoo* and *Syzygium cumini* promoted the number of grains spike^{-1} while *Psidium guajava* and *Eucalyptus camaldulensis* inhibited number of grain on higher doses of leaves. *Dalbergia sissoo* leaves have shown the most positive response to number of grains spike^{-1}, but these results are in contrast to those of Kiran and Agrihiotn (2001), who reported that grains spike^{-1} of wheat cultivars were reduced under *Dalbergia sissoo* tree canopies compared to crops growing in the open place. and Cannell (1996) suggested that shisham (*Dilbergia sissoo*) should not be planted on the boundary of farmer's wheat fields as it reduced grain yields. The present results are supported by Chander et al. (1997), who studied the positive effects of growing *Dalbergia sissoo* plantation intercropped with a wheat (*Triticum aestivum*) and cowpea (*Vigna sinensis*) cropping sequence. The inputs of organic matter through *Dalbergia sissoo* leaf litter increased and crop roots decreased with the increase in tree density. Organic matter plays a significant role in acquisition of nutrients and water, and it improves soil physical and chemical properties. It also helps in retention of nutrients in the soil particles. On the other hand, organic matter also influences the dynamics and fate of allelochemicals through different processes. Similarly, organic matter also provides a favorable site for growth of microorganisms. Moreover, these results suggest that the adoption of agroforestry can lead to improvement in organic matter status of the soils, which further enhances the growth and yield in both wheat and cowpea crops.

Effect of leaf litter on number of grains pot^{-1}

All the 5 tree species produced a higher number of grains pot^{-1} as compared to the control (Table 1). Maximum grain yield was found in T_3 (wheat with 200 g sun-dried *Dalbergia sissoo* leaves) and was at par with T_9 (wheat with 200 g sun-dried *Ficus religiosa* leaves), T_{11} (wheat with 200 g sun-dried *Syzygium cumini* leaves) and T_4 (wheat with 100 g sun-dried *Psidium guajava* leaves). Minimum number of grains pot^{-1} was found in T_1 (Control). Similarly, *Dalbergia sissoo, Ficus religiosa* and *Syzygium cumini* enhanced grain number pot^{-1} as the dose of the tree leaves increased while *Eucalyptus camaldulensis* suppressed grain yield pot^{-1} at higher doses. On the other hand, *Psidium guajava* showed no response to the increase in dose of leaves pot^{-1} (Table 2). These results are supported to those of Jamil (2003), who reported that the farmers highly preferred *Dalbergia sissoo* and *Acacia nilotica* to grow along with wheat field boundaries and the wise farmers shift these plants on the field boundary or in any other proper place. He also reported that the fallen leaves of *Dalbergia sissoo* and *Acacia nilotica* provide organic matter to crops and enhance the productivity of farms.

Effect of leaf litter on 100-grain weight (g)

100 grain weight is an important yield indicator towards final yield of wheat crops. Data presented in Tables 1 and 2 showed a different response in the case of 100 grain weight. The highest inhibition of 100 grain weight was recorded in T_7 (wheat with 200 g sun-dried *Eucalyptus camaldulensis* leaves) as compared to the control, and it was statistically similar to that of T_3 (wheat with 200 g sun-dried *Dalbergia sissoo* leaves), T_{10} (wheat with 100 g sun-dried *Syzygium cumini* leaves), T_4 (wheat with 100 g sun-dried *Psidium guajava* leaves), T_2 (wheat with 100 g sun-dried *Dalbergia sissoo* leaves). However, all other tree species were insignificant when compared with the control. With the increase in the dose of *Eucalyptus camaldulensis* leaves, the extent of inhibition in 100-grain weight was found to be enhanced. The inhibitory effects on 100-grain weight was also reported by Bisal et al. (1992), who concluded that *Eucalyptus* tree species released volatile compounds such as benzoic, cinnamic and phenolic acids, which inhibit growth of crops growing close to it and have harmful effects on germination and seedling growth of wheat, barley, lentil, chickpea, mustard and many weeds. These allelopathic chemicals have a strong potential to possibly reduce plant growth in high doses, while they promote the growth of target plants in lower amounts. These allelochemicals have vast physiological and chemical application in the overall plant internal mechanism that is being affected by the application of the water extract containing these soluble compounds. The major reason for reduced grain weight is probably the higher amount of leaf litter that proved inhibitory for wheat crops.

Effect of leaf litter on biological yield (g pot^{-1})

The final yield of wheat is a set of all yield-related traits such as plant height, number of tillers, spike length, number of spikelets per spike, number of grains per spike and 100 grain weight, which contribute to achieving high biological and grain yield in wheat. Total biological yield shows overall growth performance of the plant. All tree species significantly enhanced the biological yield of wheat crop as compared to the control (Table 1). Maximum biological yield (75.38 g pot^{-1}) was recorded in T_{11} (wheat with 200 g sun-dried *Syzygium cumini* leaves) followed by T_6 (wheat with 100 g sun-dried *Eucalyptus camaldulensis* leaves), T_4 (wheat with 100 g sun-dried *Psidium guajava* leaves) and T_3 (wheat with 200 g sun-dried *Dalbergia sissoo* leaves). Minimum biological yield (31.99 g pot ^{1}) was recorded in T_1 (control). At higher doses of leaves (200 g leaves pot^{-1}), all the tree species except *Ficus religiosa* produced similar biological yield as compared to lower doses pot^{-1} (100 g leaves pot^{-1}) (Table 3). Variation as a result of number of biological yield in grain yield was 38.75% and the relationship was positive (Figure 1). These results are in contrast to those of Hasan et al. (2005), who conducted an experiment on wheat crop, in which they treated the seeds of wheat with the extract of *Syzygium cumini* for 20 minutes. They reported that the extract reduced the germination of wheat seeds by 24% and they recorded the inhibitory effects of *Syzygium cumini*on on wheat crops.

Effect of leaf litter on grain yield (g pot^{-1})

The leaves of all the 5 tree species enhanced grain yield significantly as compared to the control (Table 1). Maximum grain yield (26.75 g pot^{-1}) and (26.69 g pot^{-1}) were recorded in T_9 (wheat with 200 g sun-dried *Ficus religiosa* leaves) and T_8 (wheat with 100 g sun-dried *Ficusreligiosa* leaves), respectively, followed by T6 (wheat with 100 g sun-dried *Eucalyptus camaldulensis* leaves), while minimum grain yield (13.81 g pot^{-1}) was recorded in T_1 (control). *Dalbergia sissoo, Psidium guajava* and *Syzygium cumini* leaves significantly produced higher grain yield as compared to their lower doses. However, *Eucalyptus camaldulensis* leaves decreased grain yield as the dose was increased (Table 3). These results are in contrast to those of Patel et al. (2002). They observed reduction in germination, growth and yield of wheat crops by eucalyptus trees. In one of their experiments, aqueous extracts of different concentrations of *Eucalyptus camaldulensis* significantly affected and reduced dry weight, germination and growth of wheat seedlings compared with the control. They further stated that the adverse effects gradually increased as the concentration increased. The probable reason for inhibition was uptake of allelochemicals in water by the seedlings and reduction in other physiological processes of wheat.

Table 3 - Allelopathic effects of leaf litter application of different tree species on wheat grain and biological yield

Treatment	Grain yield (g)	Biological yield (g)
T1	13.82 g	31.99 f
T2	20.09 e	53.83 e
T3	22.92 d	60.02 b
T4	22.84 d	60.40 b
T5	23.85 c	55.89 d
T6	25.12 b	60.91 b
T7	18.85 f	57.22 cd
T8	26.69 a	56.94 cd
T9	26.75 a	56.80 cd
T10	20.76 e	58.41 c
T11	22.70 d	75.38 a
LSD value	0.89	1.52

Different lowercase letters denote statistical differences between treatments of a cultivar at the 5% probability level according to the Least significance test. Values following the mean data are SE (n=4). T1=control; T2= *Dalbergia sissoo* leaves @ 100 g pot^{-1}; T3= *Dalbergia sissoo* leaves @ 200 g pot^{-1}; T4= *Psidium guajava* leaves @ 100 g pot^{-1}; T5= *Psidium guajava* leaves @ 200 g pot^{-1}; T6= *Eucalyptus camaldulensis* leaves @ 100 g pot^{-1}; T7= *Eucalyptus camaldulensis* leaves @ 200 g pot^{-1}; T8= *Ficus religiosa* leaves @ 100 g pot^{-1}; T9= *Ficus religiosa* leaves @ 200 g pot^{-1}; T10= *Syzygium cumini* leaves @ 100 g pot^{-1}; T11= *Syzygium cumini* leaves @ 200 g pot^{-1}.

Shoot length, shoot dry weight, number of spikelets per spike and biological yield were recorded as being the highest after the application of *Syzygium cumini* (200 g sun-dried leaves). Total number of tillers per plant and number of ears per plant had maximum values when treated with (*Eucalyptus camaldulensis* 200 g sun-dried leaves). Spike length, grain yield per pot, number of grains per pot and harvest index showed maximum performance when *Ficus religiosa* leaves (200 g) were applied. Most of the parameters were promoted at lower doses of leaves per pot; however, at higher doses, they started inhibiting the growth and yield of wheat.

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