Comparative study of wheat varieties under open farming and poplar-based agroforestry system in Uttarakhand, India

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A field experiment on wheat varieties was carried out at Agroforestry Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar. The experimental plots were laid out in randomized block design with two associate farming systems, open farming and poplar-based agroforestry system, and four varieties of wheat, viz. PBW-373, PBW-343, UP-262 and VL-907, with three replications. The average tree growth parameters, viz. plant height, diameter and crown width of poplar showed an increase at the rate of 8.43%, 12.36% and 17.91% respectively. Growth and yield attributes of wheat like germination count, leaf area index, plant height, dry matter accumulation, as well as yield of wheat were found higher in open farming compared to poplar-based agroforestry system. The yield characters of wheat, such as biological yield (112.01 q ha^{-1}), grain yield (42.19 q ha^{-1}), straw yield (69.93 q ha^{-1}) and harvest index (39.82) were recorded maximum in VL-907 followed by PBW-343, except for straw yield. Among soil chemical properties, electrical conductivity, organic carbon, and available NPK were higher, whereas pH was lower under poplar-based agroforestry system compared to open farming system. Above-ground, below-ground and total biomass, carbon stock and carbon sequestration were significantly higher in agroforestry system (130.42, 17.75, 148.17, 65.20 and 239.27 q ha^{-1} respectively) compared to open farming.

Keywords: Agroforestry, biomass, carbon sequestration, intercropping, wheat varieties.

AGROFORESTRY, when fast-growing multipurpose trees are carefully selected and grown with negligible effect on agriculture crops, adds to the sustainability of agriculture and help in its diversification to attain higher benefits per unit area without deteriorating the agro-ecosystem[1]. Its role in combating hunger, diseases and environmental degradation is highly appreciable[2]. Intercropping with high-density short-rotation tree species is the best option to meet increasing food and industrial raw material requirement through sustainable utilization of natural resources[3]. Total green cover under agroforestry system of the country is estimated at 111,554 sq. km, which is 3.39% of the country's geographical area, out of which poplar covers 1.22% of the total area under agroforestry[4]. Poplar (*Populus deltoids* Bartr.)-based agroforestry system is economically viable and more sustainable than many other crop rotations prevalent in northern and eastern India since the mid-80s (ref. 5). Its popularity among farmers is mainly due to multi-utility wood, fast growth, high market prices, less competition with associated crops and pruning-tolerant nature[6]. The cultivation of poplar under agroforestry system also improves the physical, chemical and biological properties of soil through addition of organic matter in the soil[5,7], while some negative effects have also been reported[8]. In the interspaces of poplar plantation, several seasonal crops are cultivated for enhancement of overall productivity of the land and generation of supplementary income[9]. Studies revealed that poplar-based agroforestry system increases income (>70%) and is an emergency source of cash (>20%) for plantation owners in northern India[10].

Wheat (*Triticum aestivum* L.) is grown extensively under agroforestry system in central and northern India. Poplar, due to its leaf-shedding habit before sowing of wheat in winter season, makes an excellent companion tree than other tree interfaces, and higher wheat yield under poplar compared to other tree–crop combinations in agroforestry system is reported due to its complementary effects on resource allocation[11,12]. The inherent potential of wheat under poplar-based intercropping system can be achieved by enhancing the competitive ability of wheat through appropriate and sustainable land use system. Keeping these in view, the present study aimed to assess the performance of wheat varieties under sole cropping and poplar based agroforestry system in Terai region of Uttarakhand.

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Materials and methods

Site description and experimental set-up

The study was conducted during the winter season of 2013–14 at the experimental site of Agroforestry Research Centre, G.B. Pant University of Agriculture and Technology (GBPUAT), Pantnagar, Uttarakhand (29°1′21″–29°1′43″N lat. and 79°24′3″E–79°24′19″E long, and altitude of 243.84 m amsl), which lies in the foothills of the Shivalik range of the Himalaya and North West plain agro-climatic wheat zone in the narrow strip called 'Terai'. The initial level of soil pH, electrical conductivity (EC), organic carbon, available nitrogen, phosphorus and potassium in open farming system was 7.63, 0.61 dS/m, 0.90%, 225.35 kg/ha, 18.98 kg/ha and 222.95 kg/ha and in agroforestry system it was 7.41, 0.65 dS/m, 0.94%, 226.34, 20.57 and 245.57 kg/ha respectively. The experiment was laid out in randomized block design with two systems, viz. open farming and poplar-based agri-silvicultural system, and four varieties of wheat, viz. PBW-343 (timely sown), PBW-373 (late sown), UP-262 (early sown), VL-907 (late sown), and replicated thrice. Plot size was 7 × 6 sq. m and the spacing of poplar was 7 m × 3 m. Poplar seedlings were transplanted in the experimental field on 22 February 2012. Different varieties of wheat were sown mechanically in rows at a distance of 23 cm on 14 November 2013; seed rate was 100 kg/ha. According to the soil test value, 120 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare was applied through urea, single super phosphate and murate of potash respectively. Half dose of nitrogen and full dose of phosphorus and potassium were applied at the time of sowing as a basal application, and the remaining dose of nitrogen was top-dressed at 30–35 days after sowing (DAS).

Measurement of crop growth and yield

Crop growth in terms of height was measured at 30, 60 and 90 DAS and at the time of harvest. Five plants of wheat from the sampling row of all the plots were removed with their roots intact, and their height was measured from the top of the plant to the base, excluding the roots. The leaves and tillers were weighed separately for fresh weight of the above-ground components like leaves and tillers and for roots. The samples were kept in an oven for drying at 70°C until constant weight. Leaf area index (LAI) of wheat was recorded at 30, 60 and 90 DAS. The leaf area was measured with the help of automatic leaf area meter (model: LI-COR, USA).

Plant sampling and carbon sequestration

Poplar plantations of clone G-48 (1-year-old) trees were measured for their height from the ground to the top of the trees and girth at breast height (1.37 m above the ground level). Crown spread was measured through cross-sectional crown diameter with the help of a measuring tape. Standing volume of timber tree was calculated using a regression equation: V (m^3) = 0.003487 + 0.268366 × D^2H, where V, D and H represent timber volume, diameter at breast height and height of the tree respectively[13]. The above-ground biomass was calculated using the following formula: biomass = volume × specific gravity of wood. The below-ground biomass of poplar was calculated using Intergovernmental Panel on Climate Change (IPCC) default value (0.26)[14]. To estimate the biological yield of wheat, plants were uprooted to the depth possible in 1 sq. m area. Fresh weight (above and below ground) was taken; representative samples from all treatments and replications were brought to the laboratory and dried in an oven at 60°C till constant weight was attained to record dry weight.

Results and discussion

Growth parameters of poplar tree

Average growth parameters of poplar trees showed an increase during *rabi* season 2013–14 with wheat crop at the rate of 8.43%, 12.36%, 17.91% and 15.87% in height, diameter, crown width and tree volume respectively. However, tree volume increment determined by compound interest formula (P = 100 ($n\sqrt{(D/d - 1)}$) was 16.65% (Table 1). Since volume of the tree is dependent upon height and diameter, trend in estimated standing tree volume was also the same. The crown spread depends on growth of lateral branches, but depending upon inter-cultivation practices in agri-silvicultural system, pruning of the lateral or side branches is done to facilitate more solar radiation for intercrops. Similar trend in growth of poplar under irrigated agro-ecosystem was reported earlier[15,16].

Growth parameters of wheat

All the growth parameters of wheat, viz. germination count per metre row length, LAI at 30, 60 and 90 DAS, plant height at harvest, and dry matter accumulation at harvest, were recorded higher under open farming system than under poplar-based agroforestry system (Table 2). Among the wheat varieties, VL-907 recorded higher germination count per metre row length (44.52), plant height at harvest (108.98 cm) and dry matter accumulation at harvest (112.04 q ha^{-1}), whereas highest LAI at 30, 60 and 90 DAS was recorded in UP-262 (1.79, 2.80, 4.69 respectively).

The shorter plant height of wheat under poplar plantation might be due to the shading or increase in competition for different resources with increasing age of poplar trees and the presence of poplar leaf litter mulch.

Table 1. Growth parameters of poplar tree during the experimental period, November–April 2013–14

Tree no.	Plant height (m)		Diameter at breast height (cm)		Crown width (m)		Tree volume (m^3)		Volume increment (%)	Total biomass (q ha^{-1})
	At sowing	At harvesting	At sowing	At harvesting	At sowing	At harvesting	At sowing	At harvesting		
1	4.65	5.00	6.36	7.32	2.40	2.90	0.0131	0.0156	19.23	39.58
2	3.1	3.60	6.04	6.36	–	–	0.0124	0.0141	15.18	35.77
3	4.50	5.10	3.50	4.13	2.10	2.50	0.0088	0.0098	14.85	24.86
4	5.00	5.45	4.13	5.72	2.40	2.80	0.0098	0.0118	19.87	29.94
5	6.00	6.5	7.32	7.95	3.00	3.40	0.0174	0.0202	17.65	51.25
6	4.80	5.00	6.36	6.68	2.25	2.70	0.0133	0.0142	11.39	36.03
7	4.20	4.50	4.13	4.77	2.35	2.60	0.0093	0.0105	15.80	26.64
8	4.70	5.70	7.63	8.27	3.10	3.60	0.0177	0.0207	18.10	52.52
9	4.40	5.10	6.68	7.00	2.75	3.20	0.0144	0.0157	13.20	39.83
10	5.80	6.20	6.36	6.68	2.35	2.65	0.0135	0.0145	11.97	36.79
11	4.50	4.60	4.45	5.72	–	–	0.0099	0.0119	19.77	30.19
12	4.50	5.50	6.04	6.50	2.75	3.10	0.0132	0.0145	13.77	36.79
13	5.25	4.70	3.18	3.82	1.25	1.50	0.0085	0.0091	11.64	23.09
14	5.10	5.50	5.09	5.41	2.75	3.10	0.0112	0.0122	13.20	30.95
15	6.00	6.50	7.00	7.63	3.25	3.70	0.0165	0.0192	17.76	48.71
16	5.50	6.00	7.00	7.62	2.75	3.20	0.0157	0.0182	17.54	46.17
17	5.00	5.50	6.04	6.61	1.09	2.55	0.0129	0.0173	25.70	43.89
18	4.50	4.80	5.41	6.36	2.35	2.60	0.0113	0.0133	18.51	33.74
19	5.25	5.80	6.04	7.00	2.41	2.75	0.0132	0.0162	20.96	41.10
20	5.50	5.70	6.36	7.32	2.40	2.70	0.0142	0.0169	19.18	42.88
21	5.20	5.60	6.36	7.32	2.50	2.80	0.0138	0.0167	20.16	42.37
22	3.50	3.70	3.18	3.82	1.90	2.30	0.0082	0.0089	10.86	22.58
Mean	4.86	5.27	5.66	6.36	2.40	2.83	0.0126	0.0146	16.65	37.07

Table 2. Growth parameters of wheat varieties under open farming and poplar-based agroforestry system

Treatments	Germination count per metre row length	Leaf area index			Plant height at harvest (cm)	Dry matter accumulation at harvest (q ha^{-1})
		30 DAS	60 DAS	90 DAS		
Farming systems						
Open farming	44.90	1.77	2.75	4.49	103.65	104.67
Agroforestry system	42.41	1.57	2.65	4.33	98.72	101.05
SEm ±	0.77	0.01	0.02	0.02	0.76	0.57
CD (5%)	2.34	NS	0.09	NS	NS	1.73
Wheat varieties						
PBW-343	43.85	1.72	2.58	4.38	99.31	104.93
PBW-373	43.56	1.61	2.76	4.18	93.28	97.29
UP-262	42.69	1.79	2.80	4.69	103.16	97.17
VL-907	44.52	1.59	2.67	4.38	108.98	112.04
SEm ±	1.09	0.01	0.03	0.03	1.07	0.81
CD (5%)	NS	0.04	0.14	0.09	4.50	2.45
Interaction	NS	NS	NS	NS	NS	NS
CV%	6.13	2.21	3.03	1.71	2.58	1.92

Negative effect of shading caused by poplar clone (G3) on the growth of wheat crop was reported earlier[17]. In any agroforestry system, light, moisture and nutrients are the most important factors influencing overall growth and yield of the intercrops. The variation in growth of different wheat varieties may be due to different tolerance capacity to competition for resources such as light, moisture and nutrients.

Among yield attributes and yield characters, spike length (10 cm), fertile spikelets/spike (18.41), grains/spike (39.46), grain wt/spike (1.98 g), test weight (48.85 g), grain yield (37.92 q ha^{-1}), straw yield (66.75 q ha^{-1}) and biological yield (104.67 q ha^{-1}) were recorded higher in open farming system than under poplar-based agroforestry system (Table 3). Among wheat varieties, VL-907 recorded higher spike length (9.76 cm), fertile spikelets/spike (18.33), grains/spike (43.78), grain wt/spike (2.06 g), test weight (51.28 g), grain yield (42.17 q ha^{-1}), straw yield (69.86 q ha^{-1}), biological yield (112.04 q ha^{-1}), as well as harvest index (39.82%).

Table 3. Yield attributes and yield of wheat under open and poplar based agroforestry system

Treatments	Yield attributes						Yield			
	Spike length (cm)	Fertile spikelets	Infertile spikelets	Grains/ spike	Grains weight/ spike (g)	Test weight (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest index (%)
Farming systems										
Open farming	10.00	18.41	3.41	39.46	1.98	48.85	37.92	66.75	104.67	38.75
Agroforestry system	8.61	17.16	4.75	38.06	1.78	47.29	36.74	64.31	101.05	38.93
SEm ±	0.18	0.32	0.16	0.42	0.06	0.27	0.23	0.44	0.57	0.14
CD (5%)	NS	NS	0.49	1.28	0.17	1.16	0.70	1.33	1.73	NS
Wheat varieties										
PBW-343	9.11	17.83	4.33	40.58	1.98	49.13	39.09	65.84	104.93	39.64
PBW-373	9.03	17.16	4.01	38.71	1.87	47.26	36.04	61.25	97.29	39.61
UP-262	9.31	17.83	4.00	31.96	1.62	44.59	31.99	65.17	97.17	36.30
VL-907	9.76	18.33	4.05	43.78	2.06	51.28	42.17	69.86	112.04	39.82
SEm ±	0.26	0.45	0.22	0.59	0.08	0.39	0.33	0.62	0.81	0.20
CD (5%)	NS	NS	NS	1.81	0.25	1.18	0.99	1.89	2.45	0.59
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	6.93	6.27	13.49	3.77	10.77	1.99	2.16	2.32	1.92	1.27

Table 4. Soil chemical properties after harvest of wheat under open farming and poplar based agroforestry system

Treatments	pH		Electrical conductivity (dSm^{-1})		Organic carbon (%)		Available soil N (kg ha^{-1})		Available soil P (kg ha^{-1})		Available soil K (kg ha^{-1})	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Farming systems												
Open farming	7.56	7.63	0.57	0.61	1.04	0.81	228.07	209.41	19.45	15.39	243.87	185.11
Agroforestry system	7.31	7.44	0.61	0.64	1.12	0.86	230.38	213.92	21.11	16.29	264.87	209.96
SEm ±	0.01	0.02	0.01	0.01	0.01	0.01	0.38	0.72	0.27	0.25	0.35	0.37
CD (5%)	NS	NS	NS	0.02	NS	NS	NS	NS	NS	0.77	NS	NS
Wheat varieties												
PBW-343	7.46	7.56	0.56	0.61	1.14	0.84	229.63	212.58	20.39	15.94	253.42	198.11
PBW-373	7.48	7.56	0.62	0.67	1.01	0.82	228.52	210.70	20.37	15.42	255.29	196.29
UP-262	7.41	7.49	0.60	0.61	1.05	0.78	227.55	209.78	19.61	15.93	251.06	195.36
VL-907	7.39	7.53	0.58	0.59	1.12	0.89	231.20	213.62	21.75	16.07	257.71	200.37
SEm ±	0.02	0.03	0.01	0.01	0.01	0.01	0.59	1.03	0.38	0.36	0.49	0.53
CD (5%)	NS	NS	0.02	0.03	0.04	0.01	1.62	NS	NS	NS	1.49	1.61
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	0.81	0.96	3.45	4.51	3.01	3.91	0.57	1.18	4.64	5.60	0.47	0.66

Researchers have also reported a significant reduction in the yield of crops under shade, while studying the effect of *Dalbergia sissoo* and *Acacia nilotica* on the yield of wheat and paddy[18]. Significant yield reduction in crops could be due to shading effect of trees in agroforestry system and below-ground competition for resources. Allelopathic effect is also one of the important causes of crop yield reduction in agroforestry systems[19,20].

Soil parameters

Among soil chemical properties, electrical conductivity, organic carbon, available N, P and K were higher, whereas pH was lower under poplar-based agroforestry system compared to open farming. Among wheat varieties, available N, P and K were all found maximum in the wheat variety VL-907, followed by PBW-343. Available nutrients (N, P and K) were higher in the upper 0–15 cm soil layer compared to 15–30 cm soil profile depth (Table 4).

Carbon sequestration

Above-ground biomass, below-ground biomass, total biomass, carbon stock as well as carbon sequestration were significantly higher in agroforestry system (130.42,

Table 5. Carbon sequestration (q ha^{-1}) after harvest of wheat varieties under open farming and poplar-based agroforestry system

Treatments	Biomass (trees + wheat; q ha^{-1})			Carbon stock (q ha^{-1})	Carbon sequestration (q ha^{-1})
	Above ground	Below ground	Total		
Farming systems					
Open farming	104.80	10.48	115.28	48.42	177.70
Agroforestry system	130.42	17.75	148.17	65.20	239.27
SEm ±	3.38	0.34	3.72	1.56	5.73
CD (5%)	10.35	1.03	11.39	4.78	17.55
Wheat varieties					
PBW-343	119.54	14.31	133.85	57.70	211.76
PBW-373	112.21	13.57	125.79	54.31	199.33
UP-262	111.86	13.54	125.40	54.15	198.73
VL-907	126.84	15.04	141.87	61.07	224.12
SEm ±	4.78	0.45	5.26	2.21	8.10
CD (5%)	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS
CV%	16.72	12.44	15.23	11.51	15.81

Table 6. Correlation coefficient (*r*) between wheat yield attributes

Character	Spike length	Grain per spike	Grain weight per spike	Grain yield	Straw yield	Biological yield	Harvest index
Number of tillers	0.575**	0.330	0.386	0.252	0.259	0.285	0.139
Spike length		0.300	0.590**	0.300	0.458*	0.419*	0.047
Grain/spike			0.775**	0.944**	0.452*	0.794**	0.855**
Grain weight/spike				0.726**	0.386	0.631**	0.635**
Grain yield					0.602**	0.906**	0.813**
Straw yield						0.883**	0.025
Biological yield							0.490*

**Significant at 1% level of probability; *Significant at 5% level of probability.

17.75, 148.17, 65.20 and 239.27 q ha^{-1} respectively) as compared to open farming. Among wheat varieties, VL-907 recorded maximum above-ground, below-ground and total biomass, carbon stock as well as carbon sequestration (126.84, 15.04, 141.87, 61.07 and 224.12 q ha^{-1} respectively) followed by PBW-343 (Table 5). Studies have also reported average sequestration potential in agroforestry system to be 25 t C/ha (ref. 21).

Correlation coefficient between yield attributes in wheat crop under poplar-based agroforestry system

The number of tillers showed significant correlation with spike length in wheat crop under poplar-based agroforestry system. Spike length showed significant correlation with grain weight per spike, straw yield and biological yield. Grain per spike showed significant correlation with grain weight per spike, grain yield, straw yield, biological yield and harvest index.

Grain weight per spike showed significant correlation with grain yield, biological yield and harvest index, but non-significant correlation with straw yield. Grain yield showed significant correlation with straw yield, biological yield and harvest index. Straw yield showed significant correlation coefficient with biological yield and non-significant correlation with harvest index. Biological yield showed significant correlation coefficient with harvest index (Table 6).

Conclusion

From the present study it may be concluded that growth, yield attributes and yield of wheat, above-ground, below-ground and total biomass production as well as carbon stock and carbon sequestration, and post-harvest organic carbon, available N, P and K were higher in agroforestry system than open farming. Among wheat varieties, VL-907 recorded higher yield attributes as well as grain, straw and biological yield than all other varieties.

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