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FULL-LENGTH RESEARCH ARTICLE

Agri–Silvi–Horti Systems for Semiarid Regions of North-West India

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Abstract Reduction in yield of arable crops under agroforestry in the tropics and subtropics is well known, but information on how different agroforestry systems influence the yield of crops is scanty. All types of agroforestry models may not be useful for all sites, but the old and traditional practices can be manipulated for meeting site-specific needs. Therefore, various agroforestry models (agri–silvi–horti systems) were developed to study their performance under semiarid conditions in north-west India. The experiment was conducted in ten-year-old silvi–horti systems comprising of shisham (*Dalbergia sissoo* L.) + aonla (*Embilica officinalis* Gaertn.), shisham (*D. sissoo*) + guava (*Psidium guajava* L.), khejri (*Prosopis cineraria* (L.) Druce) + aonla (*E. officinalis*) and khejri (*P. cineraria*) + guava (*P. guajava*) planted at a spacing of 6 m × 6 m. Three crop sequences, viz. cowpea (*Vigna unguiculata* (L.) Walp)—wheat (*Triticum aestivum* L.), clusterbean (*Cyamopsis tetragonoloba* (L.) Taub)—barley (*Hordeum vulgare* L.) and pearl millet (*Pennisetum americanum* (L.) R. Br.)—oat (*Avena sativa* L.), were intecropped for 2 years. The crops were also grown in open field. The fodder yield of the kharif crops, namely pearl millet, cowpea and cluster bean, was significantly suppressed by different silvi–horti systems during the period of study, and maximum yield was observed in sole cropping. Among different silvi–horti systems, maximum fodder yield of cowpea (10.27 t/ha) and clusterbean (5.67 t/ha) was recorded under khejri + guava, whereas pearl millet fodder yield (18.93 t/ha) was maximum in khejri + aonla silvi–horti system. Minimum fodder yield (3.47 t/ha) was recorded in clusterbean under shisham + guava, whereas maximum fodder yield (29.3 t/ha) was recorded in pearl millet under sole cropping. In rabi season, maximum grain yield of wheat (4.07 t/ha) and barley (4.38 t/ha) was recorded under sole cropping while minimum yield of wheat (2.34 t/ha) and barley (2.79 t/ha) was recorded under shisham + aonla. Fodder yield of oat was also influenced significantly by different silvi–horti systems. Maximum oat fodder yield of 62.00 t/ha was harvested from open field followed by 56.20 t/ha under khejri + guava. Maximum fruit yield (13.40 t/ha) was observed in aonla + wheat + khejri agri–silvi–horti system. Appreciable build up in organic carbon content (OC) and decrease in soil pH under agri–silvi–horti systems as compared to sole cropping. The available NPK content also increased under agri–silvi–horti systems and decreased with increasing soil depth. The agri–silvi–horti system of

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khejri + guava + clusterbean–barley fetched higher net returns (Rs. 76,650/ha), while the net returns from sole cropping of clusterbean–barley was only Rs. 15,953/ha.

Keywords Agri–silvi–horti · Physico-chemical properties of soil · Fodder · Yield · Aonla · Barley · Clusterbean · Cowpea · Guava · Khejri · Oat · Pearl millet

Introduction

Natural resources (land, water, vegetation etc.) are depleting rapidly due to rising population in India. The short supply of food, fiber, fodder and fuelwood has made the situation more critical. Low and erratic rainfall, poor fertility and high solar radiation have made the agriculture a risky business in arid and semiarid regions. Despite the hostile conditions, the region supports a large population of human and livestock and a variety of flora and fauna. However, the ever-increasing human and livestock population and developmental activities exert enormous pressure on the slender natural resource base of the region. Planting of trees by the farmers on their fields to meet their basic needs of food, fodder and fuelwood is common in these areas. Agroforestry is a viable option to increase the forest/tree cover from present (<25%) to 33% in the country. The plantation of poplar and eucalyptus on farmer's field in Haryana has made the state self-sufficient in industrial timber and wood [1]. Similarly, Kerala has become wood surplus state due to adoption of agroforestry [11]. Improved agroforestry systems (agri–silvi–horti) in arid and semiarid areas can meet the timber requirement of industry with basic needs of the farmers. Agroforestry has caught the attention of farmers across the world, especially in India where both forest and agricultural land are under severe stress due to population pressure and industrialization. The system has been advocated to arrest degradation and to increase fertility status of soil and enhancing yields. Productivity in agri–silvi–horticultural system is comparatively higher than the productivity of sole agriculture. Soil quality and its production capacity can be restored and improved by adopting agroforestry system like agri–silvi–horti system, which provides a way to sustain agricultural productions [26]. Similarly Kaushik et al. [9] found that integrating trees (forest and fruit) enhances overall productivities and incomes by ameliorating harsh environment of the area.

Integration of horticultural plant species provides regular income to the farmers in addition to the production from agricultural crops during the early stages of tree establishment, whereas silvicultural species provide income in later stage sustaining the long-term productivity [9]. Agri–silvi–horti system (*Prosopis cineraria* + *Ziziphus mauritiana* + wheat) had very little effect on wheat yield as an agricultural crop; thus, this system may be recommended for adoption in dry areas for fulfilling the requirements of fodder, fruit and food [23]. Improved silvi–horticultural systems provide multiple benefits and minimize the risks of total failure of system productivity as in traditional agricultural system. In addition to providing higher returns, these also improve livelihood security as a cover against crop failure due to climatic aberrations, particularly in arid and semiarid regions. However, selection of a better combination of silvicultural and horticultural species seems to be more crucial to enhance the land productivity and farmers economy as compared to single species. Hence, location-specific agroforestry models have to be developed for increasing biodiversity, water use efficiency, productivity and sustainability of the system.

Materials and Methods

Experimental Site

The studies were carried out at Chaudhary Charan Singh Haryana Agricultural University Regional Research Station, Bawal (28.1°N, 76.5°E at 266 m MSL), Haryana, India. During experimentation period, the maximum temperature reached as high as 46 °C during May and June whereas, during peak winter months of December and January, the average minimum temperature was recorded around 2 °C. The site is characterized by low (350–550 mm) and erratic rainfall during monsoon (July–September). The winter (October–March) remains almost dry. Evapotranspiration rate of 5.3 mm/day was observed during rainy (July–October) and 2.7 mm/day during winter season (November–February). The soil of the experimental site was sandy loam in texture, low in organic carbon (0.18%), medium in available phosphorus (12.0 ka ha^{-1}) and available potassium (177.0 ka ha^{-1}). The pH (1:2) of experimental field was 8.41 and EC (1:2) 0.36 dS m^{-1}.

Experimental Material and Design

Ten-year-old four silvi–horti systems, namely shisham (*Dalbergia sissoo* L.) + aonla (*Embilica officinalis* Gaertn.), shisham (*D. sissoo*) + guava (*Psidium guajava* L.), khejri (*P. cineraria* (L.) Druce) + aonla (*E. officinalis*) and khejri (*P. cineraria*) + guava (*P. guajava*), planted at a spacing of 6 m × 6 m in three replications were used for experimentation. Grafted saplings were used for fruit trees (guava and aonla), and seedlings were used for forest trees (shisham and khejri). Seedlings/saplings were protected from termite by application of chlorpyriphos (2 ml/l) with irrigation water. Three crop sequences viz., cowpea (*Vigna unguiculata* (L.) Walp)—wheat (*Triticum aestivum* L.), clusterbean (*Cyamopsis tetragonoloba* (L.) Taub)—barley (*Hordeum vulgare* L.) and pearl millet (*Pennisetum americanum* (L.) R. Br.)—oat (*Avena sativa* L.) were intercropped for two years. The crops were also raised as sole (open field). The kharif/rainy season (July–August) crops, i.e., cowpea, clusterbean and pearl millet were raised for fodder. The sowing of kharif/rainy crops in the interspaces of silvi–horti systems was done during the month of July. The kharif/rainy crops were grown on conserved moisture. The recommended package of practices was followed for growing the crops (Table 1). The crops were harvested after 55 days of sowing for fodder. The rabi/winter season (October–March) crops, namely wheat, barley, were raised for grain purpose and oat was raised for fodder. The sowing of crops was done in first fortnight of November during both years. Half dose of nitrogen and full dose of phosphorus and potash were applied at the time of sowing of winter crops. Balance nitrogen was broadcasted in two split doses after first and second irrigation. Sowing of crops was done in triplicate following recommended cultural practices (Table 1). Crops were harvested, and data were recorded on fodder, grain and straw yield and pooled for two years (10th and 11th year). Similarly, the data on fruit yield and growth were also recorded for trees and analyzed using two factorial randomized block design.

Soil Sampling and Analysis

Samples of soil were taken from each agri–silvi–horti system and sole crop plots at depths of 0–30, 30–60 and 60–90 cm during both years. Soil samples were air dried and brought to the laboratory and crushed with mallet and sieved 20 mesh for analysis. The soil pH was estimated using glass electrode pH meter method [8]. Electrical conductivity (EC) was determined by conductivity meter [8]. Organic carbon (%) was measured by Walkley and Black's rapid titration method [28]. Available nitrogen (kg ha^{-1}), available phosphorus (kg ha^{-1}) and available potassium (kg ha^{-1}) were estimated by using Kjheldhal's method [8], Olsen et al. method [13] and flame photometer method [8], respectively.

Statistical Analysis

Data were statistically analyzed after Panse and Sukhatme [14] using two-factor randomized block design. ANOVA was computed to count the differences between treatments for the characters studied. Analysis were done by using treatment mean values.

Economics

To work out the economics of the system, the cost items included the cost of saplings/seedlings, labor charges for digging pits, planting and training of trees, field ploughing charges, field preparation, cultivation of crops, material inputs such as seed and fertilizer, labor cost for different field operations including harvesting and threshing of crops, interest on working capital and rental value of land were taken from the neighboring farmers/villages. The wood volume was calculated by nondestructive method (using the girth at breast height and height) for shisham and khejri, and fire wood rates @ Rs. 500 per quintal were considered for computing returns. Returns were calculated based on prevailing market rates of fruits, grain and straw and net returns and BC ratios were calculated at discounted rate 12%.

Results

Effect of Different Agri–Silvi–Horti Systems on Yield of Crops

The yield of green fodder (kharif/rainy crops) was significantly ($P > 0.05$) less under different silvi–horti systems

Table 1 Management practices followed for raising crops

Crop	Variety	Seed rate (kg ha^{-1})	No. of irrigations	Spacing (cm)	Fertilizer (Kg ha^{-1})		
					N	P	K
Cowpea	FS-6	20.00	0.00	30.00	25.00	20.00	0.00
Clusterbean	HG-365	15.00	0.00	30.00	20.00	40.00	20.00
Pearl millet	HHB-67	10.00	0.00	30.00	75.00	10.00	0.00
Wheat	WH-711	120.00	6.00	22.00	150.00	60.00	30.00
Barely	BH-393	90.00	2.00	22.00	70.00	30.00	15.00
Oat	HJ-8	75.00	3.00	25.00	80.00	0.00	0.00

Table 2 Effect of different silvi–horti systems on green fodder yield (t/ha) of rainy crops

Tree species	Cowpea	Pearl millet	Cluster bean
Shisham + guava	9.87	15.60	3.47
Shisham + aonla	9.88	16.50	3.60
Khejri + guava	10.27	17.20	5.67
Khejri + aonla	9.90	18.93	5.60
Sole	13.00	29.30	7.47
Mean	10.60	19.50	5.16
CD ($P = 0.05$)	0.07	0.09	0.06

in comparison to control. Cowpea (13.00 t ha^{-1}), pearl millet (29.30 t ha^{-1}) and clusterbean (7.47 t ha^{-1}) showed highest yield when raised in open fields. Among four silvi–horti systems, the highest yield of cowpea (10.27 t ha^{-1}) and clusterbean (5.67 t ha^{-1}) was recorded under khejri + guava, where in pearl millet, it was maximum (18.93 t ha^{-1}) under silvi–horti system of khejri + aonla. Clusterbean yielded minimum fodder (3.47 t ha^{-1}) under shisham + guava (Table 2). In rabi also, maximum grain yield of wheat (4.07 t ha^{-1}) and barley (4.38 t ha^{-1}) was recorded under sole cropping as compared to different agri–silvi–horti systems. Minimum yield of wheat (2.34 t ha^{-1}) and barley (2.79 t ha^{-1}) was recoded under shisham + aonla, whereas maximum wheat grain yield (3.02 t ha^{-1}) was observed under khejri + guava and barley grain yield (3.89 t ha^{-1}) under khejri + aonla silvi–horticultural system (Table 3). Similarly, maximum oat fodder yield of 62.00 t ha^{-1} was harvested from open field followed by 56.20 t ha^{-1} under silvi–horti system of khejri + guava (Fig. 1). Minimum reduction (9.35%) was recorded under khejri + guava silvi–horti system, whereas, shisham + aonla showed maximum reduction (21.12%).

Effect of Different Agri–Silvi–Horticulture Systems on Growth Performance of Trees and Fruit Yield

Growth of shisham and khejri was significantly higher under agroforestry (agri–silvi–horti) systems than sole plantation (Table 4). Maximum height (9.13 m), GBH (1.00 m) and crown spread (6.69 m^2) were recorded for shisham with aonla + wheat. Khejri performed better with wheat irrespective of fruit tree species. The cultural operations and use of fertilizer and irrigation for

Table 3 Effect of different silvi–horti systems on grain and straw yield (t/ha) of winter crops

Tree species	Grain yield (t/ha)		Straw yield (t/ha)	
	Wheat	Barley	Wheat	Barley
Shisham + guava	2.92	3.14	3.64	3.92
Shisham + aonla	2.34	2.79	2.93	3.49
Khejri + guava	3.02	3.84	3.77	4.81
Khejri + aonla	2.53	3.89	3.16	4.86
Sole	4.07	4.38	5.09	5.48
Mean	2.98	3.61	3.72	4.51
CD ($P = 0.05$)	0.55	0.45	0.27	0.21

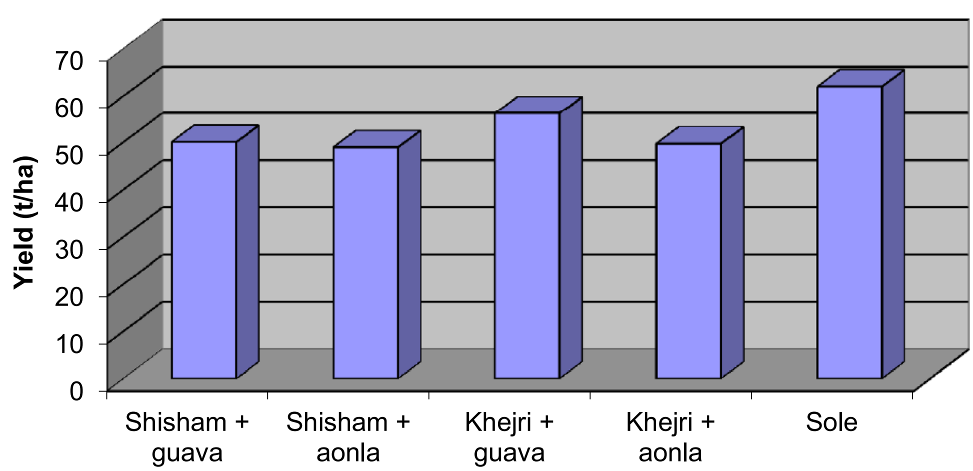

Fig. 1 Effect of different silvi–horti systems on fodder yield (t/ha) of oat

Table 4 Growth performance of different tree species under different agri–silvi–horti systems (mean of 2 years)

Treatments	Height (m)				GBH (m)				Crown spread (m^2)			
	Aonla	Guava	Shisham	Khejri	Aonla	Guava	Shisham	Khejri	Aonla	Guava	Shisham	Khejri
Sole	6.40	4.20	8.59	8.04	0.46	0.32	0.90	0.78	6.25	6.36	6.50	6.11
Cowpea–wheat	7.00	4.25	9.13	8.40	0.49	0.30	1.00	0.69	6.32	6.43	6.69	6.36
Cluster bean–barley	7.00	4.15	8.99	8.35	0.49	0.29	0.98	0.68	6.29	6.40	6.65	6.31
Pearl millet–oat	7.10	4.14	9.00	8.36	0.47	0.31	0.99	0.70	6.33	6.43	6.73	6.30
CD ($P = 0.05$)	N.S.	N.S.	0.17	0.21	N.S.	N.S.	0.07	0.07	N.S.	N.S.	0.12	0.13

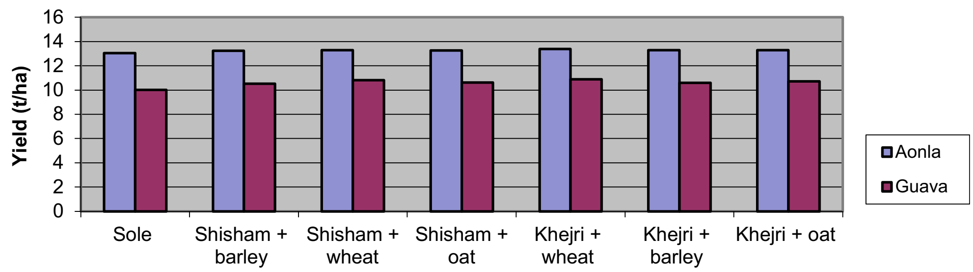

Fig. 2 Fruit yield (t/ha) of aonla and guava in agri–silvi–horticulture system

agricultural crops may also be the reason for better growth of trees observed in association with the agricultural crops. Growth of fruit plants under agri–silvi–horti system was at par with sole fruit plants; however, the fruit yield was significantly higher. Maximum fruit yield of aonla (13.40 t ha^{-1}) and guava (10.90 t ha^{-1}) was recorded with agri–silvi system of khejri + wheat in comparison to sole plantation of aonla (13.05 t ha^{-1}) and guava (10.02 t ha^{-1}) (Fig. 2). Higher fruit yield in agroforestry systems may be due to protection of fruit trees from frost during winter which helped to moderate the climate, under agri–silvi–horti system than sole plantation.

Effect of Different Agri–Silvi–Horti Systems on Soil Properties

Soil EC, pH and Organic Carbon

The mean soil EC decreased significantly with increase in soil depth irrespective of agri–silvi–horti systems, sole cropping and initial EC (Table 5). It varied among various agroforestry systems and sole cropping. There was more reduction in soil EC under agri–silvi–horti system when compared with control (open field). The EC decreased to its maximum under guava + khejri-based combinations as compared to others. The interaction among all treatments was also found significant. The mean soil pH increased significantly with the soil depth in sole cropping and silvi–horti systems whereas growing of crops did not influence the soil pH. However, the agri–silvi–horti system recorded significantly less soil pH as compared to sole crops and initial pH. The minimum soil pH was found under khejri + aonla system followed by khejri + guava, shisham + aonla and shisham + guava. The interaction between trees (silvi–horti system) and crops (agri-systems) and between crops and soil depth was found significant. However, the difference in soil pH among four agri–silvi–horti systems was nonsignificant (Table 5). The mean OC decreased significantly with deeper layers of soil irrespective of agri–silvi–horti system and sole cropping. The organic carbon content was significantly higher under agri–silvi–horti systems as compared to control (sole cropping) and initial OC. Among soil depths, the soil organic carbon was highest in the surface depths and lowest at 60–90 cm depth. In the surface depths, the increase in soil organic carbon was more under clusterbean–barley system followed by cowpea–wheat and pearl millet–oat system (Table 5). The interaction among all was also found significant.

Nutrient Status of Soil

The macronutrients (N, P, K in available form) content decreased with increase in soil depths. However, decrease was found to be significant for available N and K. The mean available N content under agri–silvi–horti was higher than sole cropping at all soil depths (Table 6); however, the increase in available N content at surface soil layer was highest. Among the four agri–silvi–horti systems, the available N content was highest under shisham + guava system with clusterbean–barley (155.00 kg ha^{-1}) and lowest in khejri + aonla with pearl millet–oat (100.00 kg ha^{-1}) as intercrops at surface soil depth (Table 6). The interactions among two systems (agroforestry and agriculture) and soil depth were significant.

Table 5 Effect of different agri–silvi–horti systems on soil EC, pH and organic carbon

Treatments	Soil depth (cm)	Ec (1:2) dS m^{-1}			pH (1:2)			OC (%)		
		Cowpea–wheat	Pearl millet–oat	Cluster bean–barley	Cowpea–wheat	Pearl millet–oat	Cluster bean–barley	Cowpea–wheat	Pearl millet–oat	Cluster bean–barley
Shisham + guava										
	0–30	0.32	0.25	0.27	8.30	8.20	8.20	0.26	0.21	0.34
	30–60	0.27	0.20	0.26	8.33	8.30	8.33	0.18	0.20	0.20
	60–90	0.23	0.20	0.24	8.40	8.35	8.35	0.18	0.15	0.17
Shisham + aonla										
	0–30	0.31	0.26	0.31	8.27	8.30	8.31	0.30	0.28	0.34
	30–60	0.26	0.21	0.25	8.37	8.43	8.33	0.21	0.22	0.19
	60–90	0.21	0.23	0.26	8.43	8.53	8.53	0.13	0.16	0.18
Khejri + guava										
	0–30	0.30	0.24	0.27	8.00	8.03	8.00	0.24	0.23	0.28
	30–60	0.24	0.21	0.22	8.20	8.13	8.07	0.14	0.17	0.15
	60–90	0.19	0.19	0.20	8.40	8.20	8.13	0.13	0.15	0.12
Khejri + aonla										
	0–30	0.32	0.26	0.26	7.87	7.97	7.83	0.24	0.23	0.29
	30–60	0.20	0.22	0.18	8.13	8.03	8.03	0.13	0.14	0.15
	60–90	0.20	0.19	0.20	8.20	8.13	8.23	0.12	0.13	0.11
Sole cropping										
	0–30	0.35	0.33	0.36	8.38	8.30	8.35	0.22	0.20	0.19
	30–60	0.32	0.30	0.31	8.41	8.38	8.39	0.15	0.13	0.14
	60–90	0.25	0.22	0.24	8.43	8.38	8.40	0.10	0.09	0.10
Initial status of soil										
	0–30	0.36	0.36	0.36	8.41	8.41	8.41	0.18	0.18	0.18
	30–60	0.34	0.34	0.34	8.50	8.50	8.50	0.14	0.14	0.14
	60–90	0.32	0.32	0.32	8.57	8.57	8.57	0.12	0.12	0.12
CD (0.05)										

Factors	EC	pH	OC
A (silvi–horti system)	0.03	0.05	0.06
B (agri-system)	0.01	NS	0.01
C (soil depth)	0.01	0.03	0.01
A × B	0.02	0.08	0.01
B × C	0.01	0.08	0.01
C × A	0.02	NS	0.01
A × B × C	0.02	NS	0.02

Similarly, the mean available P content was higher at surface soil as compared to subsurface depths. The available P content was more under agri–silvi–horti system than sole crops. The highest available P content (18.50 kg ha^{-1}) was recorded in khejri–guava system with clusterbean–barley in comparison to lowest available P content (15.95 kg ha^{-1}) under pearl millet–oat. The interaction between silvi–horti and agri-system was significant. The mean available K content was significantly higher under agri–silvi–horti system than sole cropping. Maximum potassium content (159.20 kg ha^{-1}) was recorded under khejri–guava system with cowpea–wheat crop sequence and lowest in shisham–aonla (135.47 kg ha^{-1}) with pearl millet–oat sequence. The interactions among two systems and soil depth were significant (Table 6).

Economics

Based on 2 years' average, the data revealed that agri–silvi–horti system (khejri + guava + clusterbean–barley) fetched maximum net returns (Rs. 76,650/ha) and B:C ratio (1.80). Khejri + guava + cowpea–wheat (Rs. 74,860; 1.74) and Khejri + guava + pearl millet–oat (Rs. 72,000; 1.73) were the next two agri–silvi–horti systems in terms of

Table 6 Effect of different agri–silvi–horti systems on available N, P and K content

Treatments	Soil depths (cm)	Available N ($kg\ ha^{-1}$)			Available P ($kg\ ha^{-1}$)			Available K ($kg\ ha^{-1}$)		
		Cowpea–wheat	Pearl millet–oat	Cluster bean–barley	Cowpea–wheat	Pearl millet–oat	Cluster bean–barley	Cowpea–wheat	Pearl millet–oat	Cluster bean–barley
Shisham + guava										
	0–30	120.00	101.67	155.00	16.92	16.90	14.45	136.80	146.87	144.13
	30–60	88.33	92.00	95.00	14.72	12.80	12.35	125.07	137.20	111.07
	60–90	96.67	80.67	80.00	10.76	12.00	11.50	106.80	98.47	100.53
Shisham + aonla										
	0–30	146.67	138.33	150.00	16.15	15.95	15.77	138.93	135.47	140.27
	30–60	98.33	111.67	93.33	14.24	13.70	14.47	130.13	129.73	121.07
	60–90	71.67	80.00	88.33	10.85	9.88	11.55	102.53	87.33	115.20
Khejri + guava										
	0–30	121.67	115.00	125.00	16.26	17.55	18.50	159.20	144.93	139.20
	30–60	70.00	83.33	73.33	14.42	15.90	15.40	146.53	141.73	136.93
	60–90	65.00	73.33	58.33	9.90	12.08	13.95	131.47	134.53	128.00
Khejri + aonla										
	0–30	113.33	100.00	131.67	17.15	17.75	18.10	152.67	147.47	157.07
	30–60	78.33	71.67	76.67	16.05	17.29	16.20	161.33	104.27	150.13
	60–90	50.00	55.00	47.00	11.65	11.25	13.45	140.93	113.07	109.73
Sole cropping										
	0–30	110.00	99.00	115.00	15.20	13.60	14.80	132.00	135.00	132.00
	30–60	71.00	67.00	70.00	13.60	12.85	12.80	130.00	125.00	129.00
	60–90	60.00	55.00	62.00	11.60	10.10	10.50	125.00	100.00	112.00
Initial status of soil										
	0–30	113.00	113.00	113.00	14.65	14.65	14.65	177.00	177.00	177.00
	30–60	108.20	108.20	108.20	12.60	12.60	12.60	162.70	162.70	162.70
	60–90	105.00	105.00	105.00	11.85	11.85	11.85	159.60	159.60	159.60
CD (0.05)										

Factors	Available N	Available P	Available K
A (silvi–horti system)	1.87	NS	0.58
B (agri-system)	1.32	NS	0.41
C (soil depth)	1.32	NS	0.41
A × B	3.24	5.68	0.01
B × C	3.24	NS	0.01
C × A	2.29	NS	0.72
A × B × C	5.62	NS	1.76

monetary gains (Table 7). This was certainly due to additional yield of fruits and wood from trees.

Discussion

The reduction in grain, fodder and straw yield of crops under agri–silvi–horti systems over control in this study might be ascribed to competition between tree and crop components [6, 23]. In agroforestry, the crop yield is influenced by beneficial and harmful interaction of tree and crop [5, 17]. Supply of reduced light may be the reason for yield reduction under trees [3], but different factors may be responsible for limiting the yield in different environments [4].

Minimum yield reduction was recorded under guava + khejri-based combination for all the crops tested by us. It might be due to relatively lesser reduction in light under khejri (khejri has mono-layered canopy and deep roots; [27]) as compared to other combinations. Higher crop yield under khejri tree canopy due to improved soil fertility has been reported earlier by several workers [12, 22, 29]. Kaushik and Kumar [10] also observed that khejri-based

Table 7 Economics of different agri–silvi–horticulture systems and sole cropping

Treatments	Cost of cultivation (Rs.)	Gross return (Rs.)	Net return (Rs.)	B:C	B:C (Discounted @12%)
Sole cow pea–wheat	52,540	64,500	11,960	1.23	1.48
Shisham + guava + cowpea–wheat	101,140	160,890	59,750	1.59	1.91
Shisham + aonla + cowpea–wheat	101,140	149,560	48,420	1.48	1.78
Khejri + guava + cowpea–wheat	101,140	176,000	74,860	1.74	2.09
Khejri + aonla + cowpea–wheat	101,140	166,945	65,805	1.65	1.98
Sole clusterbean–barley	45,960	61,895	15,935	1.35	1.62
Shisham + guava + clusterbean–barley	95,980	148,590	52,610	1.55	1.86
Shisham + aonla + clusterbean–barley	96,000	142,789	46,789	1.49	1.79
Khejri + guava + clusterbean–barley	96,000	172,650	76,650	1.80	2.16
Khejri + aonla + clusterbean–barley	96,000	164,000	68,000	1.70	2.04
Sole pearl millet–oat	48,750	51,400	2650	1.05	1.26
Shisham + guava + pearl millet–oat	98,000	148,260	50,260	1.51	1.81
Shisham + aonla + pearl millet–oat	98,000	144,000	46,000	1.47	1.76
Khejri + guava + pearl millet–oat	98,000	170,000	72,000	1.73	2.08
Khejri + aonla + pearl millet–oat	98,000	159,950	61,950	1.63	1.96

agroforestry model influenced the yield and growth of crops positively in both rainy and winter seasons. Guava also has positive impacts on crops grown under its canopy. Pateria et al. [16] observed the maximum productivity of wheat grown under guava might be due to the fact that guava enhanced the water holding capacity and OC.

Superior growth performance of trees under agroforestry (agri–silvi–horticulture) system than sole plantations has also been recorded by Siriri et al. [24]. Better growth in agroforestry systems might be due to cultural practices (irrigation, weeding, fertilization etc.) performed in crops or may be due to complementary root interaction between the tree species. Singh and Rathod [21] have also observed better growth in mopane trees under agroforestry plot due to better use of resources. Growth of *Achrus sapota* was 17% more when raised with leucaena. But mango showed 12% reduction in the growth when grown with casuarinas or leucaena [25]. Maximum fruit yield of aonla (13.40 t/ha) and guava (10.90 t/ha) was recorded with khejri + wheat silvi–horti system in comparison to sole plantation of aonla (13.05 t/ha) and guava (10.02 t/ha) (Fig. 2). Higher fruit yield in agri–silvi–horti systems may be due to protection of fruit trees from frost during winter which helped to moderate the climate, under agri–silvi–horticultural system than sole plantation. Reijntjes et al. [18] observed that microclimate can be influenced by planting trees that reduce the effect of frost in winter, speed of wind, evaporation, exposure to solar radiation also support our results.

The soil pH and EC values decreased in our study under agri–silvi–horticulture system when compared with monocropping. The electrical conductivity decreased to its maximum under guava + khejri-based combinations as compared to others. It may be due to more salt absorption capacity in khejri as compared to shisham as reported by Patel et al. [15] in their study of physicochemical properties of soil under different tree species. Reduction in soil pH under agri–silvi–horticulture system at top layer may be due to gradual gathering of organic matter and its subsequent decomposition, resulting in the release of weak acid [29]. Gradual gathering of litter fall resulted into higher build up of OC on soil surface. Incorporation of litter and its decomposition and incorporation would have improved the OC [20]. Differences between agri–silvi–horti systems might be due to increased or decreased quantity of litter fall over the time as well root and varying rates of decomposition of organic matter [20].

The magnitude of improvement in nutrients availability was much higher in surface soil, i.e., rhizosphere as compared to subsurface soil. The overall improvement in fertility status of soil could be credited to the regular addition of leaf litter and root decay in situ, higher microbial activity, more favorable soil conditions viz., soil moisture and temperature under trees [15]. The potential of agroforestry systems to enhance soil fertility, maintain OC and ameliorated soil ph has already been recognized [7, 19, 29]. Higher net returns from agri–silvi–horti system were due to additional yield of fruits and wood from forest trees. Similar results have also been reported by Banerjee et al. [2].

Conclusions

The site-specific study of different agri–silvi–horti systems revealed that yield of crops was affected adversely during the 10th and 11th year of tree plantation, but the overall productivity, soil fertility and economics were higher under agri–silvi–horti systems. The agri–silvi–horti system of clusterbean–barley with khejri + guava was found most remunerative as maximum net returns and BC ratios (1.80) were observed with this rotation. Fuel wood and fodder from silvicultural species and fruit from horticultural species have compensated the reduction in crop yield and resulted in higher returns in association with arable crops. The soil fertility was also improved under agri–silvi–horti systems as compared to sole cropping.

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