Doubling farmers' income through *Populus deltoides*-based agroforestry systems in northwestern India: an economic analysis

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There is widespread use of poplar in pulp and paper, match splints, pencil and plywood industries, in northern India. The practice of closer spacing geometry with compact block in poplar cultivation does not permit intercropping from the third year onwards, which discourages small landholders. In 2008, poplar was planted at the Chaudhary Charan Singh Haryana Agricultural University, Hisar, India in three spacing geometries of 5×4 m, 10×2 m and $18 \times 2 \times 2$ m (paired row) at a constant density of 500 trees ha^{-1}. In the present study, two cropping rotations (sorghum–berseem and cowpea–wheat) were intercropped in all three spacing geometries of poplar (up to eight years of rotation), and compared with sole cropping as a control. The results showed that yield of annual crops reduced considerably over the years due to enhancing competition for light, moisture and nutrients. The overall yields of annual crops in various spacing geometries of poplar were reduced by 5.67% in the second year to 45.59% in eight years of plantation. The study resulted in 10×2 m spacing of poplar with sorghum–berseem crop rotation exhibiting the highest net returns (Rs 1,191,241 ha^{-1}), NPV @ 12% discounting (Rs 409,673 ha^{-1}), B : C ratio (1 : 2.22), IRR (70%), highest land equivalent ratio (2.28) and land expectation value (Rs 2,242,372 ha^{-1}). In the study, LER and LEV calculated to increase the efficiency and adoptability of agroforestry systems. Therefore, on the basis of economics, the present study concludes that the intercropping of sorghum–berseem and cowpea–wheat in poplar planted at a spacing of 10×2 m is more profitable and helpful in doubling farmers' income over traditional agriculture in northwestern India.

Keywords: Agroforestry, economics, intercropping, land equivalent ratio, poplar.

THE 'green revolution', one of the most successful programmes for feeding millions of hungry mouths during the mid-sixties, was extensively implemented in the Indo-Gangetic region (IGR) of India. The IGR is the 'food bowl' of the country, which produces about 50% of the total food grains to feed 40% of our population[1]. In the region, rice (*Oryza sativa*) – wheat (*Triticum aestivum*) cropping system (RWCS) is a predominant traditional crop rotation spread over 53% of total area of the IGR. The RWCS of the IGR has been heavily exploited, and the indiscriminate use of fertilizers, fungicides, pesticides and other chemicals has resulted in soil degradation and unsustainable use of natural resources[2]. This could be further aggravated with deterioration of soil structure, declining underground water and water productivity, which ultimately are threats to sustainable and profitable RWCS in the region[3]. Also, the vagaries of climate change coupled with increasing fragmentation of land-holdings, extreme weather events, rising input costs and post-harvest losses pose an enormous challenge for sustaining agricultural growth. They have affected the net income from high-intensified RWCS and require urgent attention to maintain the sustainability and productivity of such fragile agro-ecosystems. For improving the profits, production and sustainability of this sequence, a paradigm shift is required. In such a situation, agroforestry is a solution to address these issues of sustainability and food security in the IGR.

Agroforestry is one of the most conspicuous land-use systems across landscapes and agro-ecological zones in India. In addition to this, it diversifies small-scale farming systems for environmental and economic functions, and is therefore considered more resilient than mono-cropping to external stresses. Agroforestry provides assets and income from wood energy, diversified crop rotations, improves soil fertility, enhancement of local climatic conditions, ecosystem services and reduces human impacts on natural forests[4,5]. Moreover, the ever-increasing demand for wood products could be minimized by growing timber trees in agriculture landscape. To address these problems, various fast-growing and industrially important tree species like poplar, eucalyptus, melia, shisham and bamboo are grown in these regions[6,7]. Among various commercial tree species, poplar (*Populus deltoides*) is widely accepted for its compatibility with agricultural crops, remunerative returns, being environment-friendly, resource conservation and low intensiveness, and it is placed ahead of traditional rice–wheat

rotation[8–11]. Currently, poplar which is one of the fastest-growing industrial soft woods, is extensively planted on an area of 270,000 ha in northern India[9]. Many research findings have highlighted that the benefits of intercropping in poplar could be more money-spinning than growing crops as a monoculture[7–11]. According to Deswal et al.[12], an average farmer earns 46% higher income from poplar-based agroforestry system (PBAS) compared to RWCS. In the light of these facts, the present study was undertaken with the objectives to evaluate the effect of spacing geometry on growth, soil and biomass production of annual crops under poplar trees at a density of 500 trees ha^{-1}, and assess the economic returns of PBAS in comparison with sole crop.

Material and methods

The study was carried out at CCS Haryana Agricultural University (CCSHAU), Hisar, India (29°10′N and 75°43′E, at an elevation of 215 m amsl), situated in the semiarid environment of northwestern India. Figure 1 presents the mean annual data of meteorological parameters during the eight years of study at the experimental site. The soil of the experimental site is sandy-loam type and medium in organic carbon, available nitrogen, phosphorus and potassium.

P. deltoides (G-3 clone) was planted during 2008 in three spacing geometries of 5 × 4 m, 10 × 2 m and 18 × 2 × 2 m (paired row) at a uniform density of 500 trees ha^{-1}. The present study was carried out from 2008 to 2016. Intercropping of two crop rotations, viz. sorghum–berseem (Sorghum bicolour–Trifolium alexandrinum) and cowpea–wheat (Vigna unguiculata–Triticum aestivum) was taken continuously under all three geometries of poplar (till the harvesting of trees) and compared with monocropping (treeless plot). Sorghum and cowpea were grown during the rainy season followed by berseem and wheat in winter, employing the standard package of practices developed by CCSHAU to cultivate annual crops.
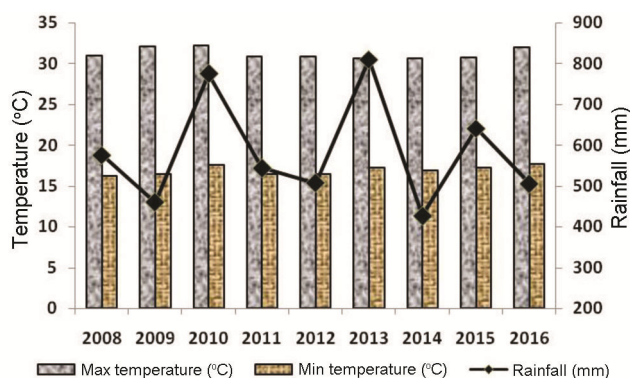
Figure 1. Mean yearly meteorological data of the study site from 2008 to 2016.

Tree height and girth at breast height (GBH)/diameter at breast height (DBH) were measured randomly using Ravi altimeter (m) and measuring tape (cm) respectively. The value (price) of trees was estimated using the purchase list of Haryana Forest Development Corporations for poplar, fixed on the girth basis for 2016 (ref. 13). In case of crops, quadrate-basis biomass yield (fresh and dry) was converted to tonnes per hectare, and price of crops was calculated on the basis of market rates during the respective years.

The soil samples were taken randomly under different spacings in three replicates from the surface soil (0–15 cm) before planting the trees and after harvesting from three geometries (at 8-years of planting), and also from control field for the study of various soil chemical properties. The soil pH, electrical conductivity, available nitrogen, available phosphorus, available potassium and organic carbon were analysed using standard methodologies.

Economic evaluations

Economic analysis was quantified by comparing different agroforestry systems with sole annual crops covering one harvest cycle of poplar. Cost components for raising the plantation were divided into the following categories: Establishment cost (A) consisted of the cost of establishment of plants incurred in the beginning of the year of planting (cost of planting material, transportation, land preparation, transplanting and plant protection). Operational cost (B) included the cost incurred in subsequent years for maintenance of the crop and tree, irrigation, fertilizer application, seed of crops, hoeing and weeding, and cultivation between the rows to avoid unwanted vegetation when no crop is grown. The interest rate on working capital (A + B) was calculated at 9%.

Other factors like management cost (10%) and risk cost (10%) with year-wise existing rental value of land were added for the estimation of financial analysis. The cost–benefit parameters used for comparison of systems were net returns, net present value (NPV) @ 12% discounting rate, internal rate of return (IRR) and benefit/cost ratio (BCR). Cost and income from intercropping as well as trees were calculated.
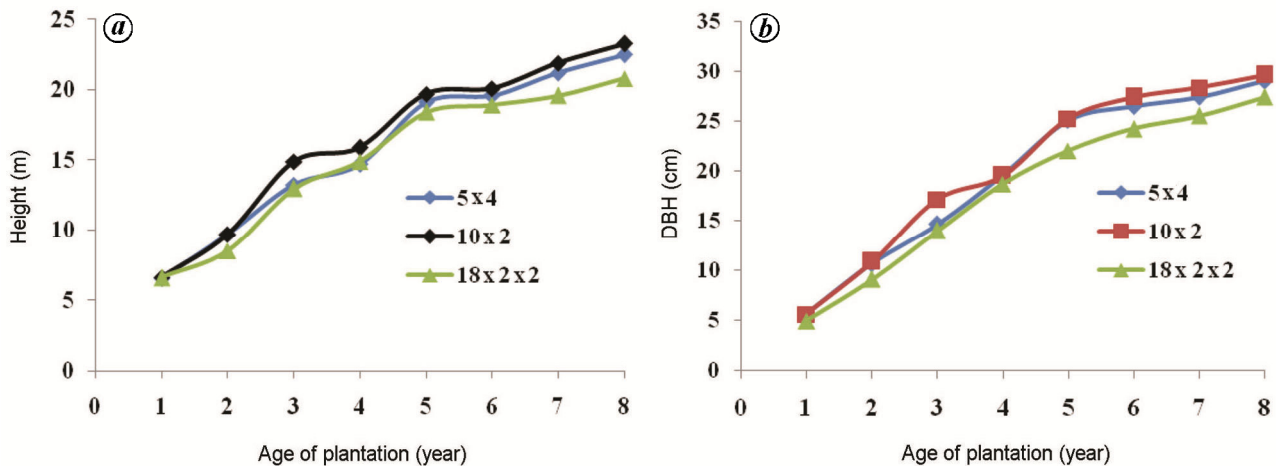
NPV was estimated as follows

$$\text{NPV} = \sum_{i=1}^{n} \frac{(B_i - C_i)}{(1+r)t^2},$$

where B represents benefits in the year t, C the costs in year t, r the selected discount rate and n is the number of years.

BCR can be expressed as follows

$$\text{BCR} = \sum_{i=1}^{n} \frac{B_i}{(1+r)^2} \bigg/ \frac{C_i}{(1+r)^2}.$$

Figure 2. (*a*) Plant height (m) and (*b*) diameter at breast height (cm) of poplar in various planting geometries from one to eight years (rotation age).

IRR is defined as that rate of discount, which equates the present value of stream of net benefits with the initial investment outlay or IRR is that rate at which the NPV of cash flow is zero.

The estimation of land expectation value (LEV) assumes that the land will be placed under a given enterprise in perpetuity with the same management[14]. We calculated LEV using the Faustmann model that combines annual revenue flow from intercropping production and final timber harvest of poplar trees.

$$\text{LEV} = \frac{\text{NPV}(1+r)^t}{(1+r)^t - 1},$$

where r is the interest (discount) rate and t is the time period.

Land equivalent ratio (LER) was used to evaluate the productivity and land-use efficiency of the mixed cropping system[15]. LER is calculated on the basis of crop equivalent yield (wheat) of commodities, biomass/yield basis and monetary basis (NPV-dependent). It is a measure of the degree to which intercropping gives higher returns to a given land area than monocropping. LER is estimated as

$$\text{LER} = Y_{pc}/Y_p + Y_{cp}/Y_c,$$

where Y_p and Y_c are the yields of poplar and crops in monoculture respectively, and Y_{pc} and Y_{cp} are the yields of poplar and crops as mixtures respectively.

When LER = (1), intercropping has no advantage over monocropping. When LER < 1, the system suffers from competition and when LER > 1, the production per unit of land surface occupied is higher than for the monocrop.

The yield and biomass of agricultural crops, soil parameters and growth traits of the trees were analysed according to method of Panse and Sukhatme[16], for statistical significance in various spacing geometries of PBAS.

Results and discussion

Growth of poplar

Tree growth parameters revealed that with the advancement of age, a gradual increase in DBH and height was observed, with maximum DBH (28.7 cm) and height (22.2 m) attained at eight years (Figure 2). The overall growth pattern of poplar followed a rising trend with age in all three spacing geometries. The height of poplar after eight years of plantation was affected significantly in different spacing geometries under agroforestry. The height and DBH of poplar in 5×4 m spacing were at par with the 10×2 m spacing, whereas the minimum tree height (20.8 m) and DBH (27.4 cm) values were recorded in paired-row spacing of poplar at the time of harvesting; this may be due to more intra-line competition of poplar plants for different growth resources. The 10×2 m and 5×4 m spacings produced 20% and 6% more growth in terms of DBH over paired-row spacing respectively. Similar trends in the growth of poplar under different spacings in irrigated ecosystem with slightly variable values have been reported by several researchers[17,18].

Influence of spacing's geometry on soil properties

Table 1 presents data on soil chemical properties (0–15 cm depth) after eight years of poplar plantation. The soil pH and electrical conductivity (EC) were found non-significant among all the spacing geometries of poplar and control. However, there was a decrease in soil pH and EC compared to its initial value in 2008. Among different spacing geometries, the highest pH (7.8) and EC

Table 1. Soil properties under different spacings of poplar-based agroforestry systems

Spacing (m)	pH (1 : 2)	EC (dSm^{-1})	Organic carbon (%)	Available nutrients (kg ha^{-1})		
				N	P	K
Initial (at the time of planting)	7.8	0.42	0.58	152	7.8	324
5 × 4	7.5	0.08	0.76	195	19.1	364
10 × 2	7.7	0.10	0.68	174	16.4	340
18 × 2 × 2	7.8	0.13	0.64	160	14.1	332
Control	8.0	0.20	0.46	140	10.8	304
CD at 5%	NS	NS	0.06	16	2.5	20

Table 2. Detailed biomass and yield of agricultural crops under poplar-based agroforestry systems

| Spacing (m)	Age of plantation (year)							Mean
	2nd	3rd	4th	5th	6th	7th	8th	
Berseem (green biomass, tonne ha^{-1})								
5 × 4 m	68.97	64.93	42.97	46.67	42.17	41.48	29.6	48.11
10 × 2 m	71.1	68	46	48.23	46.87	42.3	31.1	50.51
18 × 2 × 2 m	72.93	70.77	48.27	52.73	48.57	48	38.37	54.23
Control	74.03	72.83	55.13	55.37	52.1	55.53	46.57	58.79
CD @ 5%	1.05	1.41	0.84	3.46	1.17	1.1	1.16	
Wheat (grain yield, tonne ha^{-1})*								
5 × 4	3.81 (4.57)	3.56 (7.17)	2.68 (3.65)	2.22 (3.25)	2.04 (2.77)	2.00 (2.45)	1.85 (2.35)	2.59 (3.74)
10 × 2	3.87 (4.92)	3.66 (7.18)	3.12 (4.03)	2.56 (5.61)	2.36 (3.34)	2.1 (2.95)	2.04 (2.56)	2.82 (4.37)
18 × 2 × 2 m	3.91 (5.63)	3.79 (7.49)	3.18 (5.39)	2.82 (4.26)	2.55 (3.67)	2.5 (3.15)	2.3 (3.64)	3.01 (4.75)
Control	4 (5.29)	4.04 (5.61)	3.55 (5.06)	3.46 (4.63)	3.44 (4.31)	3.6 (5.09)	3.4 (4.65)	3.65 (4.95)
CD @ 5%	0.086 (0.10)	0.002 (0.14)	0.586 (0.10)	0.006 (0.10)	0.001 (0.01)	0.007 (0.03)	0.006 (0.01)	

*Straw yield in parentheses.
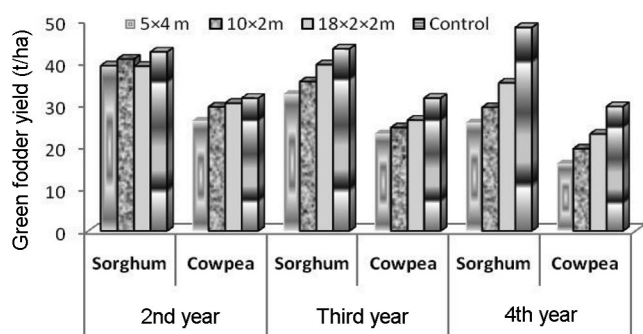
Figure 3. Green fodder biomass (t ha^{-1}) of rainy-season crops under poplar-based agroforestry system.

(0.13 dS m^{-1}) values were recorded in the 18 × 2 × 2 m spacing. The soil organic carbon (SOC) was significantly influenced by tree spacing and increased from its initial status (0.58%) under different spacing geometries of poplar-based agroforestry system. The average SOC in 5 × 4 m, 10 × 2 m, 18 × 2 × 2 m spacing geometries was higher by 64%, 50% and 41% over sole crop (control) respectively. Available nutrients (nitrogen, phosphorus and potassium) were also significantly influenced by tree spacing in the present study. The higher build-up of SOC and nutrients on the surface layer (0–15 cm) of soils may be attributed to the regular accumulation of litterfall of poplar on the soil surface and fine root turnover throughout the increasing age of trees. Similar trends have been reported in PBAS in northern India[19,20].

Yield performance of agricultural commodity

It is evident from Table 2 that green fodder biomass of sorghum, cowpea, berseem and grain yield of wheat are higher in paired-row spacing (18 × 2 × 2 m) followed by 10 × 2 m and 5 × 4 m spacing, but lower than sole cropping (devoid of trees). The performance of both rainy and winter season crops was strongly influenced under different spacing geometries of PBAS with the advancement in age of trees, thereby resulting in increased competition for solar radiation, moisture and nutrients between the trees and annual crops. The overall yield of winter crops (Table 2) was higher than rainy-season crops (Figure 3) under different spacing geometries of poplar. In the beginning, years of plantation (from two-year to four-year), green fodder biomass was noticeably reduced from 4.00% to 46.79% in sorghum and 3.71% to 46.07% in cowpea under various plant geometries of poplar over control (sole crop) (Figure 4a). In poplar-based agroforestry, fodder crops of *kharif* season were cultivated up to first
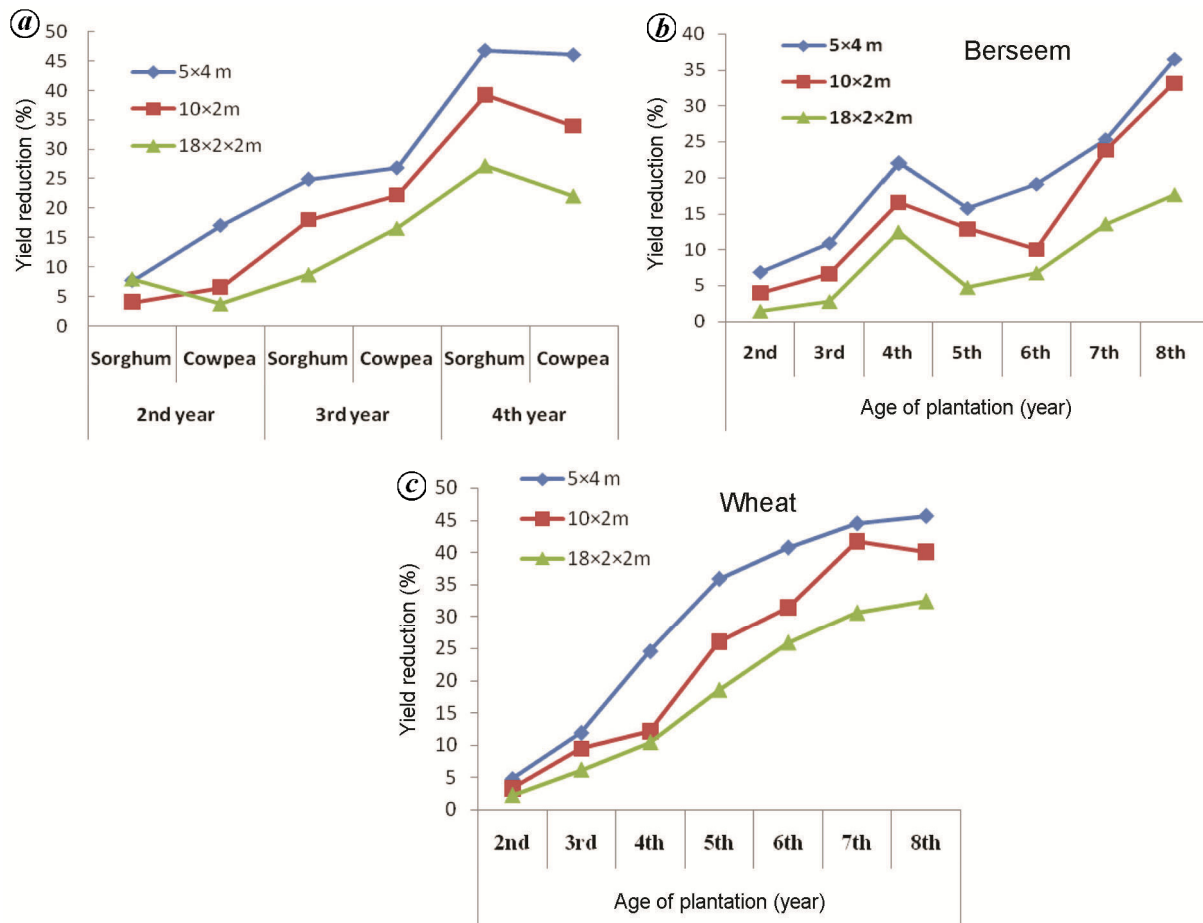
Figure 4. Yield reduction (%) of (*a*) sorghum–cowpea, (*b*) berseem and (*c*) wheat under poplar-based agroforestry system.

four years of poplar because of high reduction in yield and to increase the profit.

The performance of winter crops (berseem and wheat) in the open (crop without trees) was higher than intercropping under poplar plantation. In PBAS, yield of crops increased with the increase in distance between tree rows. In winter season, crop yield started decreasing considerably after the fourth year of plantation in 5×4 m spacing; however, reduction in yield was less under 10×2 m and $18 \times 2 \times 2$ m spacings (Table 2). The yield reduction under various planting geometries of poplar ranged from 17.00% to 36.44% in berseem and 32.45% to 45.59% in wheat during 5–8 years of plantation (Figure 4 *b* and *c*). The paired-row spacing exhibited significantly higher yield (7–33% in 2–8 year-old poplar plantations) of berseem in comparison to the 5×4 m spacing. It is a well-accepted fact that competition for light affects the yield of agricultural crops under agroforestry system over sole cropping. Many researchers have critically pointed out that yield of rainy-season crops reduces significantly than winter season crops[8,11,21,22]. This is because during rainy season, heavy shade of poplar trees hinders light interception and reduces the yield. However, leaflessness of

poplar trees in winter season provides plentiful light to the crops and results in more yield than during rainy season. Moreover, in agroforestry system, year-wise yield reduction of various crops is compensated in the form of woody biomass, and this is well-supported by various economic evaluation studies[23,24].

LER in agroforestry

LER is the ratio of the area under monocropping to the area under agroforestry, at the same level of management that gives an equal amount of yields[15,25,26]. In the present study, three methods were used to calculate LER, viz. crop-equivalent yield index, biomass basis and NPV; Figure 5 presents the results. In this study LER of both crop rotations under the three spacing geometries of poplar was above unity, and with values ranging from 1.75 to 2.28 under different spacing geometries. On the basis of LER, poplar intercropped with sorghum–berseem in a spacing of 10×2 m was found to be the best option over the other spacing geometries under the study (Figure 5). LER of 2.28 in the present study reflects that field

productivity in 1 ha area of agroforestry is equal to the crop and tree yield in 2.28 ha area when grown separately under conventional farming system. In other words, LER of 2.28 shows that 128% more land would be required to produce combined yield of all three crops if they were grown as pure stand. The results also suggest that inter-cropping with poplar under the semiarid environmental conditions maximizes the use of available resources over sole cropping. The agroforestry system provides higher LER over sole cropping, as reported by Shanmughavel and Francis[27] in bamboo, Rao et al.[26] in *Leucaena* alley cropping, and Raddad and Luukkanen[28] in *Acacia senegal* intercropping systems. Hence, maximum LER for the sorghum–berseem crop rotation in 10×2 m spacing of PBAS was reported, which would reflect a positive synergistic mutual relationship between trees and crops.

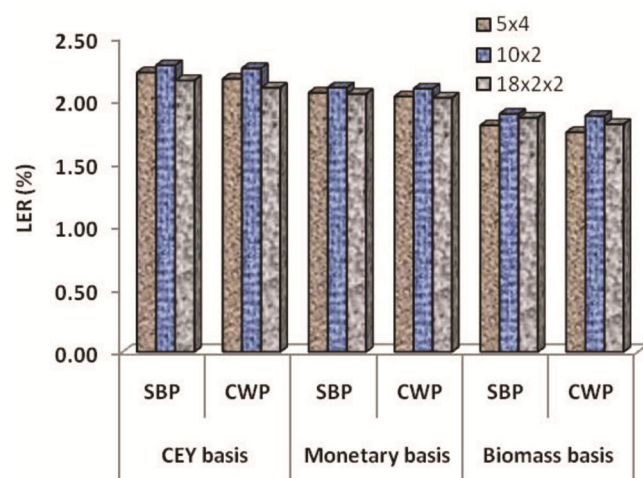*Economic analysis of poplar-based agroforestry systems*

Most of the studies on economic analysis of agroforestry system did not give the exact picture of profitability, because they were carried out as an extension survey and questionnaire-basis on secondary information from the farmers' field and market[10,24,29–31]. In the present study, however, detailed observations in terms of accurate record of rental value of land, input costs, expenditure on labour and inter-cultural operations, tree and crop growth and their yield, and market price help portray the economic overview of agroforestry systems.

Table 3 presents the detailed economic analysis of two-cropping systems (sorghum–berseem and cowpea–wheat) under three spacing geometries of poplar. The returns from PBAS during the first year were negative due to higher initial investment cost on establishment of plantation. Similar findings were also reported by various

Figure 5. Land equivalent ratio under various spacing geometries of poplar-based agroforestry. CEY, Crop eqivalent yield (wheat); Monetary basis.

workers[18,21–23,29,30]. The highest gross returns (Rs 1,800,336 ha^{-1}) and net returns (Rs 1,191,241 ha^{-1}) were obtained from sorghum–berseem crop rotation under 10×2 m spacing, followed by sorghum–berseem crop rotation (Rs 1,769,532 ha^{-1} and Rs 1,163,372 ha^{-1}) under 5×4 m spacing of poplar at eight-year rotation. However, yield of crops in $18 \times 2 \times 2$ m spacing was highest over others; but growth and biomass of poplar were less due to closer spacing (plant-to-plant) which affected the gross returns from paired-row spacing. At the end of rotation age (eight year) of poplar under different geometries and different crop combinations, the overall gross returns from the three spacing geometries of PBAS were higher in comparison to sole cropping system. However, Singh and Mavi[24] reported higher net returns of Rs 1,904,224 ha^{-1} from six-year rotation of poplar (850 trees ha^{-1}) with sugarcane in the dry sub-humid region of India having fertile soil and quality irrigation. Singh et al.[29] and Kumar et al.[31] also reported similar high net returns from PBAS (agri-silviculture system with 500 poplar trees, wheat in winter and fallow in rainy season) in northern India.

In the present study, NPV reflects the realistic picture of benefited systems through discounting the future value of present money. Highest NPV of Rs 409,673 ha^{-1} and Rs 396,815 ha^{-1} was obtained from sorghum–berseem cropping system in 10×2 m and 5×4 m spaced PBAS respectively. The higher value of NPV reflects economic efficiency of the tree-based system for adoptability and viability among farming communities. A similar trend of NPV was also reported by Kumar et al.[31] in PBAS of Haryana. The 10×2 m and 5×4 m spacing geometries equally benefited, whereas the control (sole cropping) provided very small NPV over agroforestry systems (Table 3). NPV values of the present study are higher than those reported by Rani et al.[32], where wheat–poplar-based agroforestry (500 tree ha^{-1} at five-years rotation) provided Rs 192,190 ha^{-1}.

IRR determines the maximum interest rate that a system can repay on loans while it recovers all investment and establishment as well as operational costs. The highest IRR in the present study was estimated for sorghum–berseem cropping system in paired row (73%), 5×4 m (71%) and 10×2 m (70%) spacing geometries of PBAS (Table 3). In the study, the highest IRR than discounting rate (12%) accepted because it offers renumerative returns on the investigation. However, Jain and Singh[23] in eight-year rotation (32%) and Singh and Mavi[24] in six-year rotation (59%) under PBAS had reported slightly lower IRR than in the present study. Kumar et al.[31] reported the highest IRR range from 94% to 389% for six-year rotation in PBAS. Various other studies did not mentioned IRR values of PBAS[10,29,30,32]. However, the IRR criterion is considered to be inferior to the NPV approach for profitability analysis. High IRR value of any option does not ensure high profitability from that option in NPV terms also[23].

Table 3. Details of economic analysis of poplar-based agroforestry in northwestern India (Rs ha^{-1})

| Particulars | Poplar agroforestry system | | | | | | Control Sole crops | |
| | 5 × 4 m | | 10 × 2 m | | 18 × 2 × 2 m | | | |
	SBP	CWP	SBP	CWP	SBP	CWP	SB	CW
Input cost for trees (*A*)	364,110	364,110	364,110	364,110	364,110	364,110	0	0
Input cost for crops (*B*)	242,050	297,614	244,985	298,627	249,638	299,363	691,109	773,552
Total cost (*A* + *B*)	606,160	661,724	609,095	662,738	613,748	663,474	691,109	773,552
Return from trees (*C*)	1,367,000	1,367,000	1,367,000	1,367,000	1,034,620	1,034,620	0	–
Return from crops (*D*)	402,532	344,978	433,336	387,719	485,730	420,394	754,116	685,222
Total returns (*C* + *D*)	1,769,532	1,711,978	1,800,336	1,754,719	1,520,350	1,455,014	754,116	685,222
Net present value (12% discounting)	396,815	334,293	409,673	358,133	314,782	255,004	45,880	–43,280
B : C ratio	2.20	1.92	2.22	1.98	1.93	1.70	1.13	0.9
Internal rate of return (%)	71	48	70	54	73	50	12	71
Land expectation value (Rs ha^{-1})	2,171,995	1,829,772	2,242,372	1,960,265	1,722,981	1,395,781	251,127	–236,897

SBP, Sorghum–berseem in poplar; CWP, Cowpea–wheat in poplar.

BCR is the most attractive and accepted parameter in agricultural production systems. Higher value of BCR was observed for sorghum–berseem crop rotation in 10 × 2 m (2.22) and 5 × 4 m (2.20) followed by cowpea–wheat (1.98) in 10 × 2 m spacing geometries of poplar (Table 3). The lowest value of BCR was reported in sole cropping of sorghum–berseem rotation (1.13), whereas cowpea–wheat rotation exhibited BCR less than 1.0. The sorghum–berseem crop rotation under 10 × 2 m spacing of PBAS was found to be more profitable. Some researchers have reported the higher BCR (more than 2.0) for PBAS in the Indo-Gangetic plains. According to a report of the Planning Commission, Government of India[33], the eight-year old PBAS provides NPV of Rs 190,241, BCR ratio of 3.31 and IRR of 69% at discounting rate of 12% with RWCS in northern India. With respect to financial analysis, the poplar trees contribute on an average 75% of total gross returns in the above-mentioned agroforestry systems.

LEV indicates the value of bare land in perpetual timber production in forestry[14] and is sometimes used in agroforestry[23,25]. The results of the present study indicate that sorghum–berseem cropping system (SBCR) in 10 × 2 m spacing of poplar has the highest LEV (Rs 2,242,372 ha^{-1}), followed by sorghum–berseem (Rs 2,171,995 ha^{-1}) under 5 × 4 m spacing of PBAS (Table 3). Both the crop rotations under study in PBAS give 80% higher LEV over sole cropping (control). The LEV of rice–wheat system under seven-year-old PBAS was reported to be Rs 304,843 in northern India[23]. Recently, Pandey *et al.*[25] analysed LEV for drumstick and aonla-based agri-horticulture systems and reported values of Rs 33,020 ha^{-1} and Rs 1,018,424 ha^{-1} respectively, in the semiarid region of India.

Conclusions

Economic evaluation of various agroforestry systems for adoptability is vital due to increasing land pressure and diversification of traditional cropping system. The present study shows that PBAS is economically viable and more profitable than many of the traditional crop rotations. The study concludes PBAS at spacing of 10 × 2 m is superior over other spacing geometries in terms of tree growth and crop yield. Furthermore, financial analysis shows that the adoption of such systems would help farmers to double their income (BCR of 1 : 2.22) in the semiarid environment of northwestern India, where traditional cropping system is not economically profitable (if land rent is included in the calculations). This study of PBAS right from planting to harvesting would help the farmers and various stakeholders to adopt this remunerative practice in semiarid environment of northwestern India.

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