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Yield, soil health and economics of aonla (*Emblica officinalis* Gaertn.)-based agri-horticultural systems in eastern India

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An intercropping trial was conducted during 2007–2010 on 6-year-old aonla (*Emblica officinalis* Gaertn.; cv. NA-7) orchard planted at 6 m × 6 m spacing and growing under rainfed calciorthent soil, to identify the suitable and profitable intercrops. The intercrops grown were turmeric, ginger and arbi. The results indicated that the production of fruits significantly increased due to intercrops and it was maximum in aonla in association with turmeric (13.30 tonnes/ha) followed by arbi (11.71 tonnes/ha). On the other hand, reduction in yield of intercrops was 7.5–12.0% for turmeric, 12.2–19.3% for ginger and 15.7–25.3% for arbi compared to the yield in open area without trees. It was confirmed that aonla-based agri-horticultural systems were effective in bringing about improvement in the soil properties as reflected by the significant increase in organic carbon, available nitrogen and phosphorus. Economic analysis of the systems in terms of benefits : cost ratio revealed that 'aonla + turmeric' gave a higher value (6.29) followed by 'aonla + ginger' (3.44) and 'aonla + arbi' (3.20). The interspaces of the aonla orchard in calcareous belt of eastern India could be utilized for growing various intercrops to generate substantial additional income without adverse effect on the soil fertility and productivity of the main crop.

Keywords: Aonla, economic analysis, intercrops, soil fertility.

RESOURCE degradation leading to an unsustainable production system has demanded our attention for sustainable practices to assure continued production. In this context, aonla or Indian gooseberry (*Emblica officinalis* Gaertn.)-based agri-horticultural system has immense potential to utilize and conserve rainfed area for betterment of poor farmers. Aonla being a deep-rooted deciduous tree species has a wide range of adaptability to grow in any type of soil. It is considered a highly tolerant and potential fruit species suitable for growing under salt-affected and wasteland/ravine lands. Aonla provides higher economic returns with little investments in plantation establishment and its management. Cultivation of agricultural crops

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with aonla provides an opportunity for maximum use of land surface and helps to distribute the risk due to adverse climate. The tree canopy of aonla with sparse foliage allows filtered light and permits intercropping even after the trees are fully grown. Intercropping not only generates an extra income, but also helps check soil erosion through ground coverage and improves the soil physico-chemical condition[1]. Traditionally, intercropping in the interspaces of fruit orchards is practised due to economic considerations, but only a few experimental results are available for aonla-based hortipastoral and horticultural systems[2–4]. In eastern India, no work has been carried out on the performance of aonla under intercropping system. The present study was, therefore, undertaken to know the suitability and profitability aspects of intercrops under rainfed condition in calciorthent soil of north Bihar.

The study was conducted at the Horticultural Research Station, Birauli (long. 84°40′E, lat. 25°39′N and altitude 52.92 a msl) of the Rajendra Agricultural University, Bihar during 2007–08 to 2009–10 (three years). The intercropping trial was made in a well established 6-year-old aonla orchard of cv. NA-7 planted at 6 m × 6 m spacing in 1 m^3 pits filled with 20 kg well-rotten farmyard manure, 100 g N, 50 g P_2O_5 and 75 g K_2O with the soil. Life-saving basin irrigation was provided during summer months only at 15–20 days interval for the first two years after planting and no irrigation from the third year. The site experiences subtropical climate having three distinct seasons, i.e. rainy (mid-June to September), winter (October to February) and summer (March to mid-June). Average annual rainfall during the study period was 1552 mm, of which 85% was received during monsoon months. The mean maximum temperature was 38°C (April to June) and minimum was about 8°C (January). The soil of the experimental site is a Typic calciorthent, alkaline in reaction [pH (1 : 2) 8.5], high in free $CaCO_3$ (35%), highly deficient in organic carbon (0.37%), poor in available N (166.3 kg ha^{-1}), P_2O_5 (18.5 kg ha^{-1}) and K_2O (128.2 kg ha^{-1}) with the soil texture, sandy loam (sand, silt and clay: 56, 35 and 9% respectively).

The intercrops grown were turmeric (*Curcuma domestica*, var. Rajendra Sonia), ginger (*Zingiber officinale*, var. Nadia) and arbi (*Colocassia esculenta*, var. Sahasramukhi). The intercrops were sown 1 m away from the trunk leaving an area of 3 sq. m around each tree. The experiment was laid out in a randomized block design with five replications and each replication consisted of four aonla trees in a plot size of 12 m × 12 m. Aonla tree and intercrops were also raised as sole crops for comparison. Intercrops were sown in the third week of May during 2007, 2008 and 2009. Well-rotten compost @ 20 tonnes/ha was applied to the plots 15 days before sowing the intercrops. Nitrogen, phosphorus and potash were applied as basal doses @ 120 : 50 : 100 kg ha^{-1} for turmeric, 60 : 50 : 80 kg ha^{-1} for ginger and 80 : 40 : 80 kg ha^{-1} for colocassia. The recommended spacings were adopted for different crops, like turmeric and ginger, 30 cm × 20 cm and colocassia, 45 cm × 30 cm. Other cultural practices were applied according to recommendation of the crops. The net plot size of 144 sq. m was harvested to determine the intercrop yield. After harvesting of different intercrops, composite soil samples (0–15 cm soil depth) were collected from both the cropped and uncropped land and analysed for pH, available N, P_2O_5 and K_2O using common procedures[5,6].

The data on fruit yield per plant were recorded at harvest during all the three years and were statistically analysed. Physico-chemical analyses of aonla fruits in terms of fruit weight, fruit size, pulp weight, stone weight, stone percentage, pulp : stone ratio and total soluble solids (TSS) were done on ten randomly selected, mature fruits from each replication and presented based on pooled data of three years. The TSS (°Brix) were recorded using hand refractometer. Size of the fruit was recorded with the help of vernier calipers. Observations on growth parameters of aonla in terms of height, collar girth and crown diameter were also recorded during all the three years. Marketable produce of intercrops and main crop (aonla) in terms of per hectare and their saleable value was worked out. The economics was calculated by considering the actual expenditure incurred on various operations, prevalent labour charges and current price of inputs and value of produce in the market. The net returns were computed taking into account market rates of crops.

Growth attributes like tree height, collar girth and crown diameter of aonla trees increased significantly with age and their percentage increase over the year 2007 was 41%, 56% and 33% respectively (Table 1). Irrespective of the year, all the intercropping systems showed significant enhancement in the height of the tree varying from 10% to 21% over the sole tree. Among the different intercrops, better growth of the aonla tree was observed where turmeric was grown as intercrop followed by arbi. Similar trend was also recorded with respect to collar girth. On the other hand, the increase in crown diameter due to intercropping did not show any significant difference. Better growth of aonla plants in association with intercrops may be attributed to the improved aeration from frequent soil working and to the better response of inputs applied to the intercrops than in sole plantation, where the inter spaces were left uncultivated and did not receive any additional inputs like manure, fertilizers, etc. Maximum tree growth in association with turmeric was due to application of higher doses of NPK fertilizers compared to arbi and ginger. As calcareous soils are very low in N, even a minimal amount of additional source of N helps in better growth and development of the plants. Positive influence of intercrops on growth and vigour of trees has been also reported in aonla and mango (*Mangifera indica* L.) in past studies at other places[2,7].

The physical parameters of fresh fruits of aonla as affected by different crop combinations were recorded

Table 1. Effect of intercropping on growth of aonla

Treatment	Plant height (m)				Collar girth (cm)				Crown diameter (cm)			
	2007	2008	2009	Mean	2007	2008	2009	Mean	2007	2008	2009	Mean
Aonla (sole)	5.09	6.44	6.67	6.07	51.8	64.8	77.4	64.7	4.25	5.33	5.59	5.06
Aonla + turmeric	5.85	7.53	8.73	7.37	57.5	77.5	95.1	76.7	4.85	6.07	6.58	5.83
Aonla + ginger	5.45	6.92	7.52	6.63	53.6	68.6	82.4	68.2	4.69	5.86	6.19	5.58
Aonla + arbi	5.62	7.24	8.16	7.01	55.0	71.0	85.7	70.6	4.73	5.91	6.25	5.63
Mean	5.50	7.03	7.77		54.5	70.5	85.2		4.63	5.79	6.15	
CD (P = 0.05)												
Treatment				0.51				3.4				NS
Year				1.45				14.6				1.2

Table 2. Physico-chemical composition of aonla in agri-horticultural system (average of three years)

Treatment	Fruit weight (g)	Fruit size (cm)		Pulp weight (g)	Pulp content (%)	Stone weight (g)	Stone content (%)	Pulp : stone ratio	TSS (°Brix)
		Length	Width						
Aonla (sole)	21.50	3.01	3.28	19.26	89.58	2.24	10.42	8.60	10.20
Aonla + turmeric	26.28	3.19	3.64	23.50	89.42	2.78	10.58	8.45	11.72
Aonla + ginger	21.71	3.04	3.39	19.74	90.93	1.97	9.07	10.02	10.95
Aonla + arbi	22.86	3.11	3.48	20.44	89.41	2.42	10.59	8.45	10.75
CD (P = 0.05)	2.52	0.17	0.28	3.80	NS	NS	NS	NS	NS

TSS, Total soluble solids.

immediately after the harvest (Table 2). Analysis of the data revealed that fruit weight, fruit size and pulp weight improved significantly due to growing of turmeric as intercrop under the aonla orchard. On the other hand, two other crops, i.e. ginger and arbi in association with aonla trees did not significantly improve the aforesaid attributes of aonla fruits. Higher doses of N (120 kg ha^{-1}) applied to turmeric grown under the aonla plantation might be the reason for the increase in the size of the fruits. The significant increase in the size of aonla fruit due to application of nitrogen under aonla-based agri-horticultural system was also reported by earlier workers[8]. In aonla, fruit size affects the marketing and hence is considered to be the important consideration of obtaining premium price. The pulp content, stone weight, pulp : stone ratio and TSS showed non-significant changes among the treatments.

Fruit yield of aonla during the sixth year of plantation (2007–08) gave on an average 9.20 tonnes/ha (2367.9 mm rainfall with 71 rainy days), in the seventh year (2008–09) 12.86 tonnes/ha (1535 mm rainfall with 66 rainy days), and in the eighth year (2009–10) due to poor rain and regular drought (753.7 mm rainfall with 47 rainy days) it declined up to 77% (10.04 tonnes/ha) compared with the seventh year (maximum yield; Table 3). The premature fruit drop was also observed as a major problem during the eighth year. The major cause of fruit drop might be the moisture stress during that year[9]. Fruit production was found to improve markedly by growing intercrops. The highest fruit yield (13.30 tonnes/ha) was recorded from the aonla trees in association with turmeric followed by arbi (11.71 tonnes/ha) and ginger (10.61 tonnes/ha). Minimum yield (7.18 tonnes/ha) was recorded from the trees where no intercrops were grown. The reason for increase in fruit production under agri-horticultural systems may be that manure and fertilizers applied to intercrops were also utilized by aonla trees, as there was no physical barrier between the root systems of intercrops and trees.

The magnitude of crop yield losses in agri-horticultural systems increased with the age of the trees (Table 3). This indicated that yield was inversely proportional to crown diameter. The reductions in yield of intercrops between years 6 and 8 of cultivation were 7.5–12.0% for turmeric, 12.2–19.3% for ginger and 15.7–25.3% for arbi compared to the yield in open field. Among the different intercrops, turmeric performed better with the least reduction (9.7%) in yield compared to the yield in open without aonla. Increased competition with age was due to the increased size of the trees and their ability to mop up greater resources at the expense of crops[10]. The reduction in yield under plantation is due to the fact that, in shade under plantation the crop had correspondingly lower photosynthetic rates and hence less yield[11].

Significant improvement in fertility status of soil (0–15 cm depth) in terms of organic carbon, available N and P_2O_5 was observed 8 years after planting of aonla orchard

Table 3. Yield of aonla and intercrops under agri-horticultural systems

Treatment	Aonla fruit (t/ha)				Intercrop (q/ha)			
	2007	2008	2009	Average	2007	2008	2009	Average
Aonla (sole)	5.75 (20.8)*	8.75 (31.6)	7.04 (25.4)	7.18 (25.9)	–	–	–	–
Aonla + turmeric	11.63 (42.0)	15.71 (56.7)	12.57 (45.4)	13.30 (48.0)	260.4 [7.5]**	248.2 [9.6]	227.1 [12.0]	245.2 [9.7]
Aonla + ginger	9.16 (33.1)	12.96 (46.8)	9.70 (35.0)	10.61 (38.3)	110.5 [12.2]	100.9 [16.5]	92.3 [19.3]	101.2 [16.0]
Aonla + arbi	10.24 (37.0)	14.02 (50.6)	10.86 (39.2)	11.71 (42.3)	107.6 [15.7]	102.4 [18.2]	88.7 [25.3]	99.6 [19.7]
Mean	9.20 (33.2)	12.86 (46.4)	10.04 (36.3)					
CD (P = 0.05)				1.30				

*Figures in small brackets indicate the yield of aonla fruit in 'kg/tree'.
**Figures in square bracket indicate the reduction in the yield of intercrop in percentage compared to sole-cropping.

Table 4. Effect of intercropping on fertility status of the soil in aonla orchard (after three cycles of cropping)

Treatment	Organic carbon (%)	pH (1 : 2)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)
Aonla (sole)	0.45	8.3	200.8	20.5	130.2
Aonla + turmeric	0.58	8.0	229.2	24.2	136.6
Aonla + ginger	0.49	8.1	209.8	22.6	132.5
Aonla + arbi	0.51	8.1	218.6	23.4	134.2
Initial value	0.37	8.5	166.3	18.5	128.2
CD (P = 0.05)	0.03	0.3	8.8	2.0	NS

(Table 4). The improvement in organic carbon (32.4–56.8%), available N (26.2–37.8%) and P_2O_5 (22.2–30.8%) was higher in agri-horticultural plots compared with the initial value before establishment of orchard. Sole plantation without intercrops also showed significant increase in organic carbon (21.6%), available N (20.7%) and P_2O_5 (10.8%). However, there were no significant differences in available K_2O among the plots of different treatments. The deep root system and deciduous nature helps in providing vertical drainage and incorporation of around 10 tonnes/ha of biomass for continuous improvement in physical, chemical and biological soil properties[12].

Most agroforestry systems increase soil organic carbon with the consequent increase of soil biological fertility by improving physical, chemical and biological properties of soil[13]. The organic carbon content increases due to litter production and about 20–30% of total living biomass of the tress is in the roots and through the constant addition of dead and decayed roots it improves the organic matter status of the soil[9]. Application of farmyard manure along with recommended doses of NPK fertilizers under agri-horticultural system might have influenced favourably the root growth, leading to the accumulation of organic residues and direct incorporation of organic matter in the soil.

There was no significant impact of sole plantation of aonla on pH of the calciorthent, but some reduction was observed in all the aonla plots with the intercrops. Organic acids present in the aonla leaves might have lowered the soil pH, marginally (0.2–0.5)[3]. Besides, dead root biomass and root exudates are also responsible for lowering soil pH, but low influence of acidity may be due to the presence of very high free calcium carbonate content in the soils (35%).

Aonla with turmeric resulted in the highest enhancement in the content of available nitrogen in the soil (229.2 kg/ha) followed by aonla with arbi (218.6 kg/ha) and aonla with ginger (209.8 kg/ha). Similar trend was also observed in case of available P_2O_5. The increase in available macronutrients may be ascribed to mineralization of nutrients from litter fall, fine roots and release of nutrients from the residual soil reserves[14]. Organic carbon, nitrogen and phosphorus were positively correlated, chiefly because all these attributes are intimately linked with soil humus[15]. The variation in the availability of these nutrients in the soil might be due to the nature of the intercrops and variation in their recommended doses of fertilizers applied to the plots. Higher organic matter status would have brought an optimum environment of microbial population, thus enabling quicker mineralization of organic nitrogen. Highest available N with higher doses of N fertilizer in turmeric plot might be also due to direct contribution towards the available N pool and enhancement of decomposition of the organic nitrogenous material. The increase in available P_2O_5 under agri-horticultural systems may be due to enhanced activity of phosphate-solublizing microorganisms in the soil, with appreciable quantities of organic matter. Potassium is not much influenced by soil organic matter because it is not the direct supplier of potassium. The small gain in the amount of available potassium can be attributed to

Table 5. Economic returns (Rs/ha) of different crops grown sole and in association with aonla

Treatment	Return (Rs/ha)		Gross income (a + b)	Total expenditure (c)	Net return (a + b–c)	Benefit : cost ratio
	Aonla (a)	Crop (b)				
Aonla (sole)	86,160	–	86,160	21,528	64,632	3.00
Aonla + turmeric	169,600	367,800	537,400	73,735	463,665 (399,033)*	6.29
Aonla + ginger	127,320	303,600	430,920	96,927	333,993 (269,361)*	3.45
Aonla + arbi	140,520	79,680	220,200	52,479	167,721 (103,089)*	3.20
Without aonla						
Turmeirc	–	407,100	407,100	59,383	347,717	5.86
Ginger	–	361,500	361,500	82,575	278,925	3.38
Arbi	–	99,200	99,200	38,127	61,073	1.60

*Figures in parentheses indicate additional income over sole orcharding.

improved physical and chemical soil conditions under the influence of tree cover.

Details of the cost of production and returns from the systems in association with aonla and sole crops are given in Table 5. Economic analyses of different systems showed that higher returns were obtained when the crops were grown in association with aonla, rather than sole cropping. Considering the total cost and monetary return from main and intercrops, it was found that turmeric with aonla earned maximum net returns (Rs 463,665/ha), followed by aonla + ginger (Rs 333,993/ha) and aonla + arbi (Rs 167,721/ha). These three intercropping systems estimated an additional income of Rs 399,033, 269,361 and Rs 103,089/ha respectively, over sole orcharding. It is to be noted that even at lower price of turmeric than ginger, the returns from 'aonla + turmeric' system was substantial with an overall benefit : cost ratio of 6.29. Although the benefit : cost ratio was lower in the 'aonla + arbi' system, it was two times higher than its sole crop. The increased returns from tree–crop combinations have also been reported by earlier workers in aonla-based agri-horticultural system[2].

The study showed that intercrops did not exert adverse effect on the growth and productivity of aonla. Intercropping in aonla was effective in bringing improvement in the soil fertility, leading to a sustainable production system. Turmeric, ginger and arbi can be successfully cultivated in the interspaces to generate substantial additional income (Rs 103,089–399,033) even at the sixth to eighth year of the orchard.

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