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Resource conservation and performance of *aonla* (*Emblica officinalis* Gaertn) under varying tree density and *in situ* live mulching in rainfed conditions of north west India

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ABSTRACT

A study comprising of two densities of *aonla* (D_1: 6x6m and D_2: 8x8m) and four *in-situ* live mulching options (T_1: Control; T_2: cowpea mulch; T_3: weed mulch and T_4: sunhemp mulch) was conducted in split plot design with three replications for eight years (2002 to 2009) at Selakui, Dehradun. Influence of different tree density and residue input to soil due to different live mulch options on vegetative growth and fruit yield and quality of *aonla* as well as soil and *in-situ* rain water conservation was evaluated in *aonla* based agri-horti system with rainfed maize-wheat/mustard sequence on 2.0% sloping land provided with multi-slot devisors. D_1 (277 trees ha^{-1}) significantly enhanced tree height (15.0%), fruit yield (37.7%) and litter fall (47.8%) besides 47.0% reduction in soil loss over D_2 (156 trees ha^{-1}). D_2 also significantly improved crown spread, girth at breast height (GBH), fruit weight and TSS: acid ratio than D_1 by 13.2, 9.0, 15.0 and 5.0%, respectively which may be attributed due to lower tree-tree interface on account of more space plant^{-1} that directly relates to higher availability and utilization of growth resources mainly the moisture and nutrients. Different residue inputs to soil (variable in C:N ratio and quantity) under distinct live mulch options invariably improved aonla tree growth, fruit yield and quality over the control. T_4 treatment outperformed other live mulch options and recorded maximum improvement in tree height, crown spread, GBH, fruit yield and litter yield that was equivalent to 16, 13, 9.0, 27 and 40%, respectively over unmulched control. Among interactions (DxT), D_1T_4 recorded significantly higher tree height (3.54 m), crown spread (689.73 m^2 ha^{-1}), fruit yield (8.14 t ha^{-1}), litter yield (3.27 t ha^{-1}) and moisture conservation (57.65%) but variations in tree height were statistically at par with D_1T_3 (3.36 m). Similarly, D_2T_4 also recorded significantly higher crown spread (2.78 m^2 tree^{-1}), GBH (29.3 cm), fruit yield (35.63 kg ha^{-1}), litter yield (14.74 kg tree^{-1}) and fruit weight (42.2 g) but variations were statistically at par with D_1T_2 in crown spread (2.69 m^2 tree^{-1}) and with D_2T_3 in litter yield (13.21 kg tree^{-1}). Significantly higher TSS: Acid ratio was produced by D_1T_2 (5.35). D_1T_4 recorded minimum soil loss (4.90 t ha^{-1}) and runoff (17.50%) and led to significantly higher moisture conservation (57.45%). The higher BC ratio (1.49) was observed in case of D_1T_4 followed by D_1T_2 with a net return of `194935 and 164425 ha^{-1} was produced due to fruits and dry wood biomass.

Key words :
Biological yield,
Crop residues,
Net return,
Plant density,
Vegetative growth

1. INTRODUCTION

Aonla (*Emblica officinalis* Gaertn), known for its nutraceutical properties, is an important indigenous, under-exploited and spring deciduous fruit plant that thrives well in subtropical to tropical climate. In North India, *aonla* flowers in March, fruit setting takes place in April and thereafter fruit experiences dormancy till onset of monsoon, fruit development starts hereafter and maturity is attained in December to January. Performance of *aonla* is well proven in rainfed conditions and on salt affected soils. The phenology of NA-7 cultivar of aonla is most suited to agroforestry due to comparatively lesser canopy spread than any other cultivar. It has inherited characters of favorable canopy architecture, sparse foliage, branching pattern, thin canopy *etc.* that leads to better radiant energy penetration for under storey crops. *Aonla* is widely grown in association of several crops in other regions also (Doharey *et al.,* 2011). NA-7 recorded maximum fruit productivity under rainfed condition of Doon valley on degraded lands (Rathore *et al.,* 2011).

Tree density is a prime factor to govern space tree^{-1} and ultimately the growth and productivity of tree species on account of availability of growth resources mainly the moisture and nutrients in sole and agroforstry plantations. Tree density directly influences tree-tree and tree crop interface which profoundly governs the overall productivity of agroforestry systems. Tree density also has major role in reducing runoff and soil loss and moisture conservation on sloping lands, litter input, soil fertility build up, live carbon sink and microclimate modifications (Young, 2002; Montagini and Nair, 2004). Higher tree density enhances canopy cover that retards runoff and soil loss which increases fruit productivity on account of more *in-situ* rain water conservation and nutrient benefits due to litterfall *etc.* on sloping lands. Higher tree density enhances time of concentration, stay of rain water on soil surface and water infiltration at greater depth in soil profile. However, standardization of *aonla* tree density for sustained and higher fruit productivity, *in-situ* rain water conservation, retarding soil loss and soil fertility and nutrient benefits is completely lacking on sloping agricultural lands of North West (N-W) India in Doon valley. Organic mulching (incorporation of the live weed, sunhemp and crop residues) sustains higher agricultural productivity during rainy and winter seasons on sloping agricultural lands in rainfed production system due to enhancement in the soil and *in-situ* rain water conservation and fertility build up (Khola *et al.*, 2000; Sharma *et al*., 2011) but the influence of live mulches on productivity and quality production of fruit crops particularly in post monsoon sceniaro where adequate soil moisture becomes vital for fruit development and maturity, has yet not been studied in agroforestry systems in N-W India. A very little information is available on Indian gooseberry or *aonla* but literature is silent on *in-situ* moisture conservation during post monsoon season that may be of high significance during fruit development to maturity as well as for fruit quality on sloping lands of outer foothills of Himalayas.

Share of rainfed and irrigated sectors of agriculture in total fruit production (63 m tons) in India is approximately 80 and 20%, respectively (NRRA, 2010) but this production level is insufficient to fulfill the nutritional requirement of burgeoning Indian population. Doon valley, situated in outer foot hills of Himalays, is characterized by soils of varying capability and slopes in a fragile eco-system beset with highly unpredictable with erratic rainfall pattern that give rise to heavy soil loss, meager *in-situ* conservation of rain water that ultimately hatches droughts of variable duration and intensity. Both, meager *in-situ* rain water conservation and heavy soil loss becomes a prime production constraint in rainfed farming from point of view of sustainable agricultural. Fruit based models are main source of livelihood food security and environmental quality in north western Himalaya, India (Rathore *et al.,* 2014). The area affected due to soil erosion is 11.2, 6.5, 9.9, 7.1 and 4.0% under soil erosion category of moderate (10-15 t ha^{-1}yr^{-1}), moderate severe (15-20 t ha^{-1}yr^{-1}), severe (20-40 t ha^{-1}yr^{-1}), very severe (40-80 t ha^{-1}yr^{-1}) and extra severe categories (>80 t ha^{-1}yr^{-1}), respectively (Anonymous, 2010). In India, 5334 m tons of productive soil is lost every year (Dhrunarayana and Ram Babu, 1983) out of which major portion is lost from nearly 80 m ha of cultivated lands. Fruit based land use may be a feasible, viable and profitable options to reduce high runoff and sediment yield and bring it within or below the permissible soil erosion limits (5 to 12 t ha^{-1}) from point of view of nutritional security of burgeoning population in the country (Dhrunarayana, 1993). Therefore, in backdrop of quite meager studies on fruit productivity and soil erosion under different tree density and potential live mulch options to maximize residue input to soil for nutrient and moisture benefits as well as improving the fruit quality and yields, an experiment was conducted to develop suitable aonla based agri-horti system in rainfed production system on 2% sloping land in Doon Valley in N-W India.

2. MATERIALS AND METHODS

Study Area

The study was conducted at Dhulkot block of Indian Institute of Soil and Water Conservation, Research Farm, Selakui, Dehradun (latitude-30^{0}20'40", longitude-78^{0}02" E and elevation: 680 m amsl) in Doon valley (between outer foothills of Himalaya and Shivalik). The mean annual rainfall of 1320.6 mm was received during period under reference out of which 78.53% was received during crop period in *kharif* and 9.22% during *rabi.* Mean monthly average minimum and maximum temperature during study were 12.52^{0}C during January and 27.55^{0}C during May. However, mean monthly maximum temperature of 41.52^{o}C during May and mean monthly minimum temperature of 1.2^{0}C during January, were recorded. Minimum and maximum wind velocity recorded during growth phase of aonla was 0.32 km hr^{-1} during October and 1.74 km hr^{-1} during May, respectively.

Experimental Details

Soil of experimental site was a stablized class II land of a silty clay loam texture (fine loamy mixed Hyperthermic Udic Haplustaff) having poor status of nitrogen, medium status of phosphorus and high status of potassium with pH of 6.3 and field capacity of 23.91%. The study was conducted in split-split plot design with three replications and treatments involving two *aonla* plant densities in main plot (D_1=277 and D_2=156 trees ha^{-1}), four *in-situ* live mulch options in sub plot (T_1: control or without crop residue in the basin, T_2: *in-situ* cowpea live mulch in the plant basin, T_3: *in-situ* live weed mulch, and T_4: live *in-situ* sunhemp mulch in the plant basin). Mulch of weeds, sunhemp and cowpea residues were applied @ 20 kg uniformly in the plant basin. Four aonla trees were kept as an experimental unit in each main plot. One year old budded *aonla* seedlings of NA-7 cultivar were planted in the month of August, 2002 in pits of one cu m after filling with recommended quantities of soil, farm yard manure, fertilizers and insecticides (survival more than 90% and necessary gap filling with two years old seedlings in July, 2003). A fertilizer dose of 100 g N, 50 g P and 100 g K $tree^{-1}$ was applied during the first year and multiplicative dose of NPK with age of *aonla* plants were given from first year onwards and were fixed as 1.0 kg N, 0.5 kg P and 1.0 kg K at 10^{th} year of *aonla* plantation. Normal recommended package of practices were adopted uniformly for raising maize in rainy season (June to September) and *aonla* in all the treatments. The *in-situ* live mulch treatments were created in maize crop (Cv Kanchan) sown at 90 x 20 cm by seed drill by sowing two rows of cowpea (Cv. Komal) in inter spaces of maize as intercrop to create T_2 while seeds of sunhemp (60 kg ha^{-1}) was brodcasted immediately after maize sowing followed by planking to create T_4 treatment. Sunhemp was cut and spread at 35-40 days while cowpea was used live mulch after picking green pods since it matures and dries earlier and partially decays before maize harvest. Live weed mulch was created at 20-25 days at manual weeding.

Litterfall

Litter fall of *aonla* was collected with the help of litter collection tray of standard size placed at four directions during litter fall period (February-April) for the entire period from each site. Four trays (1x1m) were placed at each direction for litter collection. Fresh weight of samples was taken by electronic balance. Litter fall biomass was calculated based on oven dried weight for all the samples and expressed in t ha^{-1}.

Soil Moisture

Soil sampling was done at monthly interval from October to mid June every year (2002 to 2009) up to 100 cm soil depth with the help of soil auger. Available soil moisture was determined by gravimetric method and expressed as (%) for 0 to 100 cm soil depth.

Fruit Yield and Quality Attributes

Data on vegetative growth parameters of aonla trees (plant height, trunk diameter, canopy spread, *etc.)* were recoded each year in month of Nov.-Dec. when vegetative growth was completed just before dormancy period (March) in North India. Data on fruit yield, quality parameters (fruit weight, stone weight, pulp weight and Juice percentage) and yield contributing characters (fruit size, weight and chemical characteristics *viz.,* TSS, total sugar and acidity) were recorded each year on maturity during 2006 to 2009. Ten mature fruits were collected randomly from each cultivar for analysis of physico-chemical properties. Fruit size with the help of vernier caliper, Titrable acidity by N/10 NaOH solution and TSS through hand refractometer was estimated. Tree canopy area was calculated on the basis of mean canopy diameter [(north-south + east-west)/2] using thread and meter scale. Tree height was measured using straight poles and meter scale while tree GBH was measured by vernier caliper.

Economic Analysis

All input data like seeds, budded *aonla*, fertilizers, farm yard manure, pesticides, irrigation, labour and machinery hours were utilized during 2002-2009 and outputs as fruit yield of *aonla* were recorded annually during 2006-2009 through systematic monitoring. All inputs and outputs were converted into monetary values to express them in a common unit. For this, average price of each input/output over period of study was worked out to account for yearly price fluctuations. Government prices were utilized if available; otherwise, local farm-gate prices were used. Year wise total cost and total returns were estimated for each treatment to draw the inference of benefit: cost ratio.

3. RESULTS AND DISCUSSION

Litter Yield

Tree litter production potential holds a high significance from point of view of improvement in soil carbon sink, fertility build up, water holding potential and physico-chemical soil properties. As such litter input to soil has a key role in sustained higher quality productivity. Data (Table 1) revealed that D_2 produced significantly higher litter yield $tree^{-1}$ (23.71%) than D_1 which may be attributed due to 77.78% more space $tree^{-1}$ (64 M^2) than D_1 (36 M^2). More space $tree^{-1}$ minimized tree-tree interface and enhanced availability and utilization of key growth resources (moisture and nutrients) in D_2. However, D_1 recorded significantly higher litter yield ha^{-1} than D_2 that was equivalent to 49.74%. This may be attributed due to higher number of trees in unit land area (277 trees ha^{-1}) revealing that higher litter yield ha^{-1} was not associated with litter yield $tree^{-1}$ but with the number of trees ha^{-1} (enhancement in litter yield by 950 kg ha^{-1} in D_1 over D_2). Different live mulch options also recorded significant variations in litter yield $tree^{-1}$ and ha^{-1}. Live sunhemp mulch recorded significantly higher litter yield $tree^{-1}$ and ha^{-1} but variations were statistically at par with live weed mulch in litter yield $tree^{-1}$ and with cowpea mulch in litter yield ha^{-1}. This shows that leguminous residues of sunhemp (narrow C:N ratio) significantly enhanced litter production that on mineralization and led to nutrient and moisture benefits to aonla trees. This also revealed that recycling weed residues and its mineralization also promoted the litter yield $tree^{-1}$

Table: 1
Vegetative growth parameters, fruit yield and litter fall in *aonla* as influenced by different tree density and *in-situ* live mulch options on 2% slope in rainfed conditions of Doon valley

Treatments	Tree height (m)	Crown spread (m^2 $tree^{-1}$)	Crown spread (m^2 ha^{-1})	GBH (cm)	Fruit yield (kg $tree^{-1}$)	Fruit yield (t ha^{-1})	Litter yield (kg $tree^{-1}$)	Litter yield (t ha^{-1})
D_1	3.26	2.30	637.10	24.60	24.17	6.70	24.17	2.86
D_2	2.96	2.60	405.99	26.80	29.90	4.67	29.90	1.91
CD (5%)	0.05	0.25	230.45	2.00	4.24	2.00	2.80	0.85
T_1	2.84	2.27	483.42	24.50	22.39	4.65	9.21	1.96
T_2	3.00	2.52	533.15	25.65	28.43	6.00	10.90	2.55
T_3	3.24	2.39	507.91	25.00	24.81	5.23	12.07	2.31
T_4	3.36	2.64	561.71	27.00	32.51	6.85	13.27	2.74
CD (5%)	0.20	0.15	25.45	0.65	2.42	0.60	1.70	0.35
$D_1 T_1$	2.93	2.15	595.55	23.90	19.13	5.30	8.56	2.37
$D_1 T_2$	3.21	2.34	614.94	24.60	25.81	7.15	10.00	3.03
$D_1 T_3$	3.36	2.22	648.18	24.00	22.34	6.19	10.94	2.77
$D_1 T_4$	3.54	2.49	689.73	25.90	29.38	8.14	11.81	3.27
$D_2 T_1$	2.75	2.38	371.28	25.10	25.64	4.00	9.87	1.54
$D_2 T_2$	2.78	2.69	399.36	26.70	31.05	4.84	11.79	2.06
$D_2 T_3$	3.12	2.56	419.64	26.00	27.28	4.26	13.21	1.84
$D_2 T_4$	3.18	2.78	433.68	29.30	35.63	5.56	14.74	2.20
CD (5%)	0.20	0.15	25.45	0.65	2.42	0.60	1.70	0.35

again on account of nutrient and moisture benefits but the effect was not so pronounced as to produce significantly higher litter yield ha^{-1}. However, net impact of nutrient and moisture benefits of leguminous residues of cowpea was more pronounced than weed residues having wide C:N ratio as it produced litter yield ha^{-1} at par with the live sunhemp residues. These point out that narrow C:N ratio residues of leguminous mulches were most suited to litter yield $tree^{-1}$ and ha^{-1} area. Different DxT interactions also significant variation in litter yield $tree^{-1}$ and ha^{-1}. D_2T_4 produced significantly higher litter yield $tree^{-1}$ but variations were statistically at par with D_2T_3 again revealing that the interaction of more space $tree^{-1}$ and live mulch with sunhemp and weeds produced substantially more litter yield $tree^{-1}$. D_1T_4 recorded significantly higher litter yield ha^{-1} but variations were at par with D_1T_2 reconfirming that high tree density and leguminous residues of sunhemp and cowpea favored higher litter yield ha^{-1} while low tree density and leguminous mulch residues favored higher litter $tree^{-1}$.

Vegetative Growth Parameters

Data on vegetative growth parameters (Table 1) revealed that D_1 recorded significantly higher tree height and crown spread ha^{-1} than D_2 treatment which was equivalent to 10.1 and 56.93%, respectively. This is again attributed due to higher number of trees ha^{-1}. On the other hand, D_2 recorded significantly higher crown spread $tree^{-1}$ (13.04%) and girth at breast height (8.94%) than D_1 which clearly again established the favorable effect of more space $plant^{-1}$ and associated benefits arising out of the more availability and utilization of growth resources mainly the moisture and nutrients. All live mulch options enhanced vegetative growth of *aonla* trees in order of sunhemp > cowpea > weeds over unmulched control having no distinct residue input benefit. However, variations in tree height between T_3 and T_4 and variations in crown spread $tree^{-1}$ between T_2 and T_4 were statistically at par. This clearly established that different residue inputs to soil that had varying C:N ratio; recorded significant variations in different parameters of vegetative growth of *aonla* trees on account of nutrient and moisture benefits. Variations in vegetative growth of *aonla* trees under different live mulch options may be attributed due to variations in mineralization of residues of live mulches and coincide of nutrient release with different periods round the year wherein active nutrient uptake rate by *aonla* trees varied. Sunhemp live mulch enhanced plant height, crown spread $tree^{-1}$, crown spread ha^{-1} and girth at breast height over unmulched control by 18.3, 16.3, 16.2 and 10.2%, respectively. Sunhemp residues also revealed the highest nutrient and moisture benefits as is evident from vegetative growth of *aonla* trees among different live mulching options. D_1T_4 produced significantly higher and maximum tree height and crown spread per ha but variations were statistically at par with D_1T_3 in tree height. D_2T_4 recorded maximum crown spread $tree^{-1}$ and girth at breast height but variations in tree height were statistically at par with D_1T_2. This reveals that regardless of tree density, leguminous mulch material (mainly live sunhemp) improved different vegetative growth parameters of *aonla* trees except tree height where cowpea and weed materials also produced favorable effect at par with sunhemp. Minimum vegetative growth (crown spread, GBH, fruit yield and litter yield) of *aonla* was observed in D_1T_1 revealing that lack of live mulching drastically reduced the tree growth (Table 1).

However, tree height was found minimum in D_2T_1. Thus, this study establishes the significance of application of *in-situ* live mulch material in general and of sunhemp in particular so far as vegetative growth of aonla trees in agri-horti system in N-W India is concerned.

Soil and *in-situ* Rain Water Conservation

Soil erosion is a serious problem on sloping agricultural lands that not only depletes soil but also leads to loss of lot of essential plant nutrients, soil organic matter and fine soil particles mainly the clay fraction that is chemical active part of soil from point of view of nutrient retention and cation exchange. Fig. 1 and Fig. 2 indicate that canopy area significantly reduced soil erosion and runoff were inversely related to canopy cover ha^{-1} (more soil and water conservation in D_1). As canopy area of *aonla* trees increased over the years, soil erosion decreased accordingly in comparison to fallow plot. This established that agroforestry is a key practice for soil and *in situ* rain water conservation in high rainfall submountainous N-W India. Initial canopy area of *aonla* was 79.0 and 51.4 $m^2 ha^{-1}$ under D_1 and D_2, respectively in 2002 with maximum soil erosion (11.46 t ha^{-1}) in fallow plot. This erosion rate was brought down up to 6.64 and 8.82 t ha^{-1} when *aonla* plants attained full canopy at the age of eight years and covered an area of 3443 and 2341 $m^2 ha^{-1}$ under D_1 and D_2, respectively in 2010. *Aonla* trees attained full canopy at 8^{th} year of plantation which reduced 33 and 23% soil erosion that not only resulted in saving of top fertile soil but also improved soil health and fertility.

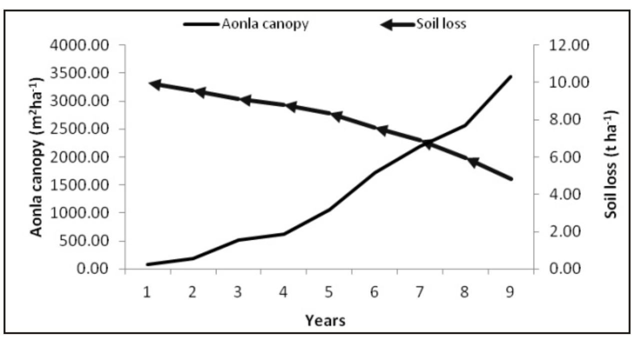

Fig. 1. Effect of *aonla* canopy on soil loss (t ha^{-1}) in high density plantation (277 plants ha^{-1})

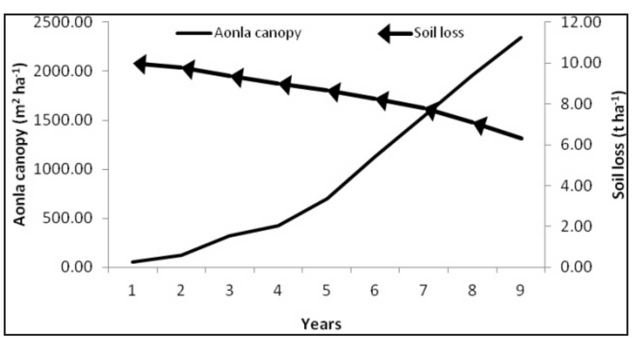

Fig. 2. Effect of *aonla* canopy on soil loss (t ha^{-1}) in normal density plantation (156 plants ha^{-1})

Dhruvanarayana (1993) advocated that fruit based land use can reduce the soil loss up to permissible limit of 5 to 12 t $ha^{-1}yr^{-1}$ on sloping agricultural lands (11%) under different management practices.

Data (Table 2) revealed that high density plantation (D_1) retarded both sediment yield (10.01%) and runoff (6.57%) which led to 8.98% higher moisture conservation over D_2. This may be attributed due to 56.93% higher ground cover in one ha area on account of 77.56% higher number of trees. Live sunhemp mulch significantly retarded both runoff and soil loss beides significantly improving the moisture conservation over unmulched control but variations were statistically at par with live cowpea mulch in sediment yield ha^{-1} as well as in runoff per cent with both cowpea and weed mulches. Notably, sunhemp mulch recorded significantly higher improvement in moisture conservation over all other live mulch options in this establishing superiority of this biological material in rainfed production system of N-W India not only in terms of resource conservation but also in terms of fruit yield $tree^{-1}$ and ha^{-1}; fruit weight; TSS: acid ratio and litter yield $tree^{-1}$ and ha^{-1}. D_1T_4 produced significantly lower sediment yield ha^{-1} but variations were statistically at par with D_2T_4. Similarly, D_1T_4 produced lower runoff but variations were at par with other D x T interactions except D_1T_1 and D_2T_1 (both unmulched control). This revealed that all live mulch options significantly lowered sediment yield and runoff over unmulched control thus, were of worth for resource conservation in rainfed production system of N-W India. Besides, recording maximum soil and *in-situ* rain water conservation, D_1T_4 also outperformed in moisture conservation.

Fruit Yield and Quality Parameters

Data (Table 1 and Table 2) revealed that tree density (D), live mulch residues (T) and interaction of these two factors (D x T) significantly improved fruit yield and quality parameters (fruit weight and TSS: acid ratio). D_2 significantly increased fruit yield $tree^{-1}$ (23.71%), fruit weight (15.5%) and TSS: acid ratio (2.2%) over D_1 revealing that more availability and utilization of nutrients, moisture and radiant energy that improved fruit yield and quality parameters. Among various live mulch options, sunhemp significantly improved fruit yield $tree^{-1}$, fruit yield ha^{-1} and fruit weight but significantly higher TSS: acid raio was recorded under cowpea mulch. This revealed that leguminous mulch materials having narrow C:N ratio quickly mineralized and confered nutrient benefit to *aonla* trees that improved the yield and quality parameters of *aonla* fruits in agri-hort system under rainfed conditions of N-W India. The maximum fruit weight (42.20 g) and TSS: acid raio (5.45) was recorded in D_2T_4 interaction. *Aonla* trees in D_2T_4 interaction attained more vegetative growth and canopy area $tree^{-1}$ due to higher availability and utilization of nutrients, moisture (due to sunhemp mulch) and sunlight that enhanced food manufacture and physiological efficiency of *aonla* trees ultimately resulting in more food supply to developing fruits that led to production of fruit of bigger size than D_1. TSS: acid ratio was also enhanced under D_2 which may be attributed due to lower moisture conservation and availability than D_1. Doharey *et al.* (2011) also recorded better fruit quality under recommended (wider) spacing of aonla. More total soluble solids present in the fruits indicated less water content which increased storage life span and disease resistance by creating anti-microbial environment. TSS and acidity are indicators of sweetness and sourness, respectively. The blending of sugar and acidity gives good flavour and taste. Singh *et al*. (2009) reported that fruit quality in *aonla* improved by application of crop residues or mulch due to conservation of more moisture and addition of organic matter to the soil after decomposition of mulches. Kumar *et. al*. (2014) revealed that mulching improved fruit quality of apple under rainfed situation. Sunlight influences growth and development of fruit trees by influencing photosynthesis that constitutes basic source of energy for all plant processes (transpiration, metabolites synthesis, organs movement, *etc.*) that ultimately governs plant morphology. Radiant energy becomes a limiting factor in high density fruit tree plantations that accommodate more number of trees unit^{-1} area. This initiates competition for sunlight which results in more tree height. High density *aonla* plantation produced more biological yield (fruit and litter) in a unit area as it accommodated 78% more number of trees than 8x8m spacing. In the present study, high density *aonla* plantation produced fruit yield of 6.7 t ha^{-1} at four-year bearing age which is 43.5% higher than *aonla* plantation at 8x8m. Ram *et al.* (2001) also reported 62% more fruit yield in high plant density than normal density plantations of mango at Pantnagar. Sunhemp live mulch increased vegetative growth (plant height, crown spread and girth at breast height) which ultimately improved fruit and litter yield on account of more organic matter, nutrient mineralization from residues conservation of moisture; whereas in 8x8m spacing, more vegetative growth was recorded with respect to canopy spread tree^{-1} and girth at breast height. These results are supported by Doharey *et al.* (2011) who reported that addition of organic mulches improved vegetative growth and fruit yield of *aonla* by conserving more moisture in the soil profile.

Economics

Economic evaluation (Table 3) revealed that maximum net income (₹ 1,94,935 ha^{-1}) and cost benefit ratio (1:1.49) was realized in *aonla* planted at 6x6m spacing with sunhemp mulch by selling of fruits followed by *aonla* planted at 6x6m spacing with cowpea mulch. In 8x8m *aonla* plantations, net return of ₹ 1,23,415 ha^{-1} and cost benefit ratio of 1:1.25 was recorded under sunhemp mulching followed by *aonla* planted at 8x8m spacing with cowpea mulch. The net return in 6x6m *aonla* plantation was 26% more than 8x8m spacing *aonla* plantation under same treatment because it accommodates 78% more plants ha^{-1}. Kumar and Shukla (2010) have also reported that aonla fruit based production system is more profitable than other fruit based land uses under rainfed conditions of Bundelkhand. Mango based agri-horti models are more economically riable than sole mango cultivation upto 15th year of age (Rathore *et al.,* 2013).

4. CONCLUSIONS

The present experiment conducted in rainfed condition of Doon valley in N-W India on 2% sloping lands clearly established that out of four options of live mulching in

Table: 2
Fruit quality, soil loss, runoff and moisture conservation in *aonla* as influenced by different tree density and *in-situ* live mulch options on 2% slope in rainfed conditions of Doon valley

Treatments	Fruit weight (g)	TSS (^{0}Brix)	TSS: Acid ratio	Soil loss (t ha^{-1})	Runoff (%)	Moisture conservation (%)
D_1	29.60	10.38	5.00	6.95	18.43	49.02
D_2	34.20	10.60	5.11	7.65	19.64	44.98
CD (5%)	3.90	NS	0.05	0.50	1.06	3.96
T_1	25.50	10.95	4.98	10.25	21.25	41.52
T_2	34.10	10.45	5.20	5.70	18.09	47.94
T_3	29.70	10.40	4.98	8.25	18.83	44.52
T_4	38.40	10.15	5.08	5.00	17.98	54.04
CD (5%)	4.20	NS	0.10	2.00	2.42	3.00
$D_1 T_1$	23.90	11.00	5.00	9.50	20.60	42.54
$D_1 T_2$	31.80	10.40	5.05	5.50	17.58	49.50
$D_1 T_3$	28.30	10.10	4.95	7.90	18.05	46.60
$D_1 T_4$	34.50	10.00	5.00	4.90	17.50	57.45
$D_2 T_1$	27.00	10.90	4.95	11.00	21.90	40.50
$D_2 T_2$	36.30	10.50	5.35	5.90	18.60	46.37
$D_2 T_3$	31.10	10.70	5.00	8.60	19.60	42.43
$D_2 T_4$	42.20	10.30	5.15	5.10	18.46	50.63
CD (5%)	4.20	NS	0.10	2.00	2.42	3.00

Table: 3
Cost of cultivation of *aonla* (₹ ha^{-1}) under different treatments

Treatments	Fruit yield (t ha^{-1})	Total return (₹)	Total inputs (₹)	Net return (₹)	B:C ratio
D_1	6.70	2,68,000	1,23,149	1,44,851	1.18
D_2	4.67	1,86,800	89,376	97,424	1.09
T_1	4.65	1,86,000	99,376	86,624	0.87
T_2	6.00	2,40,000	1,11,278	1,28,722	1.16
T_3	5.23	2,09,200	1,05,238	1,03,962	0.99
T_4	6.85	2,74,000	1,24,588	1,49,412	1.20
D_1T_1	5.30	2,12,000	1,00,254	1,11,746	1.11
D_1T_2	7.15	2,86,000	1,21,575	1,64,425	1.35
D_1T_3	6.19	2,47,600	1,10,266	1,37,334	1.25
D_1T_4	8.14	3,25,600	1,30,665	1,94,935	1.49
D_2T_1	4.00	1,60,000	80,456	79,544	0.99
D_2T_2	4.84	1,93,600	85,356	1,08,244	1.27
D_2T_3	4.26	1,70,400	82,488	87,912	1.07
D_2T_4	5.56	2,22,400	98,985	1,23,415	1.25

Note: Total inputs were considered from 2002 to 2009, Total returns considered from 2006 to 2009, Farm gate fruit selling price were used @ ₹ 10 kg^{-1}.

maize crop and *aonla* basins, sunhemp mulch significantly enhanced fruit yield and quality attributes, litter yield tree^{-1} and ha^{-1}, moisture conservation as well as economic returns apart from substantially reducing runoff and soil loss. *Aonla* plantation (277 plants ha^{-1}) at 6x6m spacing recorded higher return due to fruits and fire wood *i.e.* of ₹ 1,94,935 than low density plantation at 8x8m spacing (₹ 1,23,415 ha^{-1}). 6x6m *aonla* plantation (277 plants ha^{-1}) also significantly reduced soil loss and recorded more fruit yield, net returns and moisture conservation in association with live sunhemp mulch in rainfed conditions of Doon valley. Thus, live sunhemp mulch in association with aonla density (277 plants ha^{-1}) at 6x6m spacing was the most suitable land use on 2% class II lands in Doon valley of N-W India.

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