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Stem pruning severities affect growth, physiological and quality consequences in high density planting system of mango (*Mangifera indica*) in Shiwalik foothills

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ABSTRACT

The study evaluated the influence of shoot pruning intensities on physiological and quality consequences of mango under square system of planting between 2014 and 2016 in Shiwalik foothills. Three mango cultivars, viz. Mallika, Dashehari, and Amrapali, planted under high density were selected purposely. Tip pruning of frost injured shoots significantly influenced growth, flowering, yield and quality traits of the cultivars compared to un-pruned trees. The results revealed early flower initiation with peak period of flowering among the treatments. Shoot pruning slightly delayed but more uniform flowering comparative to control. After 20th harvest season, the cultivar significantly affected generative parameters (TCSA, TCV, CA and yield efficiency). Number of sprouted shoots per scaffold branch (primary, secondary) was highest in Dashehari followed by Amrapali and Mallika irrespective of shoot differentiation. Dashehari recorded maximum length of panicles, length of flowering shoot, number of panicles/shoot, fruited panicles, fruit set, and fruit retention with least fruit drop when the shoots were pruned in frost affected twigs (terminal branches) shoot differentiation. The best yield and yield efficiency over the 20th leaf harvest was recorded in Mallika followed by Amrapali and Dashehari. Variable shoot pruning intensities showed significant effects on fruit physical-biochemical traits and foliar nutrient concentration of the cultivars. DOP indexing showed close agreement to diagnose N, P, K, Mg, Fe, Cu, Zn and Mn excess among different cultivars studied. PCA of agro-morphometric and fruit quality traits was also worked out. prin4 accounted for 99.5% (agro-morphometric traits) and 97.9% (fruit quality) of the cumulative variance of cultivars. PCA-F1 had the highest positive loadings (plant height, tree girth, annual shoot extension growth TCSA, and TCV) followed by PCA-F2 (yield). None of the significant differences were obtained when the calculated factor scores of PCA-F1, PCA-F2 and PCA-F3 for attributes analyzed. Conclusively, shoot tip pruning could be recommended for restoring maximum production and quality fruits in high density square planting system of mango.

Key words: Frost injury, Head back, Rejuvenation, Tip pruning

Mango (*Mangifera indica* L.) is delicious and relished fruit crop in the sub-tropical and tropical world, containing vitamin A, C and minerals. India ranks first among mango producing countries accounting more than 60% of the world's mango production, occupies 22.2 lakh ha of the total cultivated area with national production of 8.49 million tonnes (NHB 2015). The orchards in north India are becoming old with dense and overcrowded canopy structures (Lal *et al.* 2001). In old overcrowded trees, light interception and utilization by the photosynthetic surface of orchard is reduced. Shoot pruning/ heading back is an unavoidable necessity of virtually all arboreal fruit crops and adopted to maintain proper physiological balance between vegetative and reproductive crop load. Therefore, it is pre-requisite to have annual shoot tip pruning that shall provide reliable synchronized flowering year after year to have frequent flushes, especially in humid tropics (Davenport 2006). The improved cultivars often showed sharp decline in yield and quality after 10 years of fruiting which ascribed to overlapping or intermingling of branches, poor light interception and photosynthesis, non-availability of productive shoots and high incidence of pests and diseases (Singh *et al.* 2010). The young flushes are cut back to mature wood, the resulted flush was floral one caused due to tip pruning which reduced tree size (Poffley and Owens 2006). Massive rejuvenation is advocated for enhancing production potential of old and senile orchards through top working and head-backing operations. Besides, during December to February, the frost played havoc in burning the foliage, tender twigs and flowering buds in Paonta valley of Shiwalik foothills. In the past, judicious pruning and stem differentiation of mango has been advocated to obtain

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optimum fruit yield and growth parameters (Chauhan *et al.* 2013). Beneficial and favourable effects of shoot pruning in mango have been earlier reported on light interception and total leaf chlorophylls, growth (Lal *et al.* 2001), yield and regularity in bearing (Lal and Mishra 2007, Shinde *et al.* 2003).

Tip pruning encouraged frequent flowering and branching of young trees into annual production year earlier than when left alone, stimulated early flushes of lateral stems to maintain tree size and prepared trees for synchronous flowering. Lal *et al.* (2001) documented the favourable effects of different intensities of shoot pruning in mango on light interception, chlorophyll content in leaves of pruned trees and yield. The growth responses to the shoot differentiation being carried out by a number of mango growers have led to some interesting insights. The present study, therefore, was performed to evaluate rejuvenation pruning to recommend the practice of shoot differentiation to the fruited shoots for the next season after harvest as a measure to maintain the size of mango trees. The second objective of the study was to rejuvenate the frost injured mango trees to evaluate its effect on flowering intensity, cropping ability and fruit quality traits.

MATERIALS AND METHODS

Three mango cultivars, *viz*. Amrapali, Mallika and Dashehari were planted at 3 × 3 m under high density orcharding at RHRTS of YSPUHF, Dhaulakuan, Sirmour, Himachal Pradesh, India. The experimental orchards were established in the year 1997. The orchard is situated at an altitude of 468 m above mean sea level, lies between coordinates of 30°30'20" North latitude and 77°20'30" East longitude. The experiment was laid out for three consecutive seasons between 2014 and 2016. The trees of uniform age group (20 year) were planted in north-south row orientation. The cultivars were raised on wild mango stone seedling rootstock. This planting spacing resulted into tree density of 1111 trees/ha.The trees were also maintained under uniform cultural practices during the entire course of investigation.

The experimental area experienced sub-tropical climate with annual rainfall of about 1100 mm with dry and windy season having an maximum average temperature 37°C and minimum of 8°C (March to June). The rainy season extends from July to September receiving 85-90% of total annual rainfall. This is warm period with high humidity and severe winters (even minimum temperature of -2°C) associated with severe pooled frost from December to February, resulted in complete burning of foliage and twigs. The intensity of frost was so high that the bud initiation and differentiation was ceased in the ensuing spring season. Therefore, the removal of dried twigs, in scientific way, became inevitable to get the frost injured mango trees to be rejuvenated. The experimental soil was texturally sandy loam alluvial, towards neutral in reaction (6.85 pH, 1:2 soil water suspension), 0.21 d/Sm of electrical conductivity (EC) and 4.5 g/kg of soil organic carbon (OC). The experimental site had an initial alkaline $KMnO_4$ extractable)-N (309.6 mg/kg), Olsen-P (11.5 mg/kg), NH_4OAC-K (329.4 mg/kg). DTPA-extractable micronutrients cations namely, Zn, Mn, Fe and Cu were 1.93, 44.8, 57.7 and 1.89 mg/kg, respectively.

The experiment was arranged as RCBD factorial with four replicates, eight trees per treatment selected for each season for each cultivar. There were three rows of each variety comprising 24 plants in each row. Shoot differentiation was carried out in mid-March 2008 with the following 5 pruning severities, T_1: Head back from first order stem differentiation (main trunk); T_2: Head back from second stem differentiation (first order); T_3: Head back from third stem differentiation (second order); T_4: Head back from fourth stem differentiation (third order); T_5: Tip pruning of frost affected twigs (terminal branches), and T_6: Unpruned (control). The balanced pruning was performed in all directions of the canopy, which were dense and over-crowded. The outer branches were headed back to remove the new shoots which developed after harvest the preceding season.

To measure the plant height (m) from the lowest scaffold branch, the distance between graft union to end of the highest branch in main trunk was recorded. The representative sample of uniform and healthy fruiting and flush bearing shoots were selected randomly from all the four directions (east, west, north and south) to measure the annual shoot extension growth in July and expressed in centimeter (cm). Canopy diameter (tree spread) was measured in both the direction (north-south and east-west) of the canopy. Length of flowering shoot, and the tree trunk circumference (at 15 cm above the graft union) were measured using a digital caliper, and then used to calculate the trunk cross-sectional area (TCSA, cm^2) using formula (TCSA= $girth^2/4\pi$) as described by Kumar *et al.* (2008). The traits namely, number of sprouted shoots per branch, shoot length, tree canopy volume (TCV), trunk girth (TG) were recorded at flowering phase in each experimental year. The number of sprouted shoots/ branch was recorded by counting the number of new shoots. TCV was determined by calculating total above ground volume of each tree from height and spread method (Westwood 1978). For leaf area (LA, cm^2) estimation, the representative sample size of 50 fully expanded and matured leaves was taken from all over the tree canopy (Nii *et al.* 1995), and was calculated using the equation, Y= -0.146+0.706X, where Y= leaf area and X = leaf length × width.

The flowering period was recorded at full bloom in the mid-March to mid-April, using full-tree panicle cluster count. The number of panicles formed per tagged shoot was counted. The represented sample size of thirty shoots was tagged under each treatment (5 per replicate) for recording the observations on length panicle, length of flowering shoot and fruited panicles. Floral measurements comprised of all parameters recorded under flowering activities. The time of panicle emergence was recorded (as date of appearance of first panicle) on the tagged branches after pruning. Total number of flowers was counted on each panicle and fruit set was determined as fruit set (%) = (number of fruitlets/

panicle at pea stage/number of flowers) × 100. Similarly, the fruit drop at weekly intervals up to the harvest was recorded by counting the number of fruits retained per panicle at 30th day interval after pea stage (initial fruit set) using formula, fruit drop (%) = [(number of fruits at pea stage per panicle-number of fruits per panicle at different intervals after pea stage) / number of fruits per panicle at pea stage] × 100.

Yield (kg/tree) of each cultivar following stem differentiation treatment was measured in each commercial harvest in three replicates. The cumulative yield (2014-2016) was determined. The tree trunk circumference measured used to work out yield efficiency (calculated as a ratio of yield/tree in kg/cm of TCSA, kg/m of TCV, kg/m of CA and kg/m of LA) according to Westwood (1978). Subsequently, mean alternate bearing index (ABI) from 2014 through 2016 was estimated according to the equation: ABI=1/(n-1) $\times\{|a_2-a_1|/(a_2+a_1) +|a_3-a_2|/(a_3+a_2) + \ldots .. +|a_n-a_n\text{-}1|/(a_n+a_{n-1})\}$, where, n=number of years, and a_1, a_2. . ., a_{n-1}, a_n=yield of the corresponding years (Stenzel and Neves 2004). Fruit samples were harvested randomly from each cultivar at fully ripe stage (physiological maturity) based on fruit firmness, size and typical variety colour in July to mid of August. The harvested fruits were then utilized for analyzing fruit quality characteristics. Sample of 10 fruits in three replicates per treatment (*n*=60) was measured for the fruit quality traits. The variables, viz. fruit dimensions the length and width of fruit samples were measured with a digital caliper i.e. fruit fresh weight (g) was determined using an electronic balance; fruit firmness was determined using Effegi Penetrometer model FT; total soluble solids (TSS) was evaluated at 25±2°C of all sampled fruits at consumer maturity with a hand refractometer (°Brix, °B); titratable acidity (TA); TSS:TA ratio was also calculated, and sugars (reducing sugars, non-reducing sugars and total sugars) were estimated according to AOAC (1980).

The chemical properties of soils were determined according to standard methods. Soil pH and EC were measured in 1:2.5 soil-water suspensions. Soil OC was analyzed according to Walkey and Black (1934), available N by alkaline potassium permanganate method (Subbiah and Asija 1956), P (0.5 M $NaHCO_3$ extractable) by Olsen *et al.* (1954) and 1N neutral ammonium acetate extractable and K was estimated by flame photometry (Merwin and Peach 1951). Meso-nutrients (exchangeable Ca, Mg) were determined according to ammonium acetate method (Black 1965). DTPA extractable Fe, Cu, Zn and Mn, was buffered at pH 7.3±0.05 according to Lindsay and Norvell (1978), and analyzed using atomic absorption spectrophotometer. To measure mineral nutrient concentration in plant tissues, each foliage sample comprised 50 leaves from middle of the shoot (non-fruiting and non-flushing) from December flush were taken during the month of April (Kumar and Nauriyal 1978). Leaf sampling and their preparation for chemical analysis was carried out (Chapman 1964 and Samra *et al.* 1978). The digestion of leaf sample (1 g) for the estimation of total N was carried out in concentrated H_2SO_4, contained a digestion mixture of potassium sulphate (400 parts), $CuSO_4$ (20 parts) and selenium powder (1 part). For the estimation of P, K and B, the samples (0.5 g) were digested in diacid mixture (HNO_4:$HClO_4$) in the ratio of 4:1 (Piper 1966). Total leaf N was determined using a nitrogen auto-analyzer, Kjeltech Foss Tecator model 2300, and P by the phosphovanadomolybdate method (Jackson 1973). K concentration was determined by Atomic Emission Spectroscopy, whereas, micronutrients were quantified on atomic absorption spectroscopy.

The deviation from optimum percentage (DOP) index is capable of accurately defining the quantity and quality of each nutrient in plants: optimum (DOP=0), deficiency (DOP<0) or excess (DOP>0) computed according to Montañés *et al.* (1991, 1993). The absolute value of DOP index indicates the significance or severity of an anomalous nutritional status. The DOP index based on leaf analysis is calculated using general formula, DOP= $\{C_n/C_o\text{-}1\} \times 100$, where, C_n= foliar concentration of the tested nutrient, and C_o= critical optimum (reference) nutrient concentration. The C_0 was taken from optimum values, proposed by Samra *et al.* (1979) and Samra (1988) in mango. Besides, it provides the general nutritional status of nutrients through the ΣDOP index, and obtained by adding the values of DOP index irrespective of sign during the study years. The larger the ΣDOP value, the greater is the intensity of imbalances among nutrients and the lower the ΣDOP value, the greater is the intensity of balance among nutrients.

Statistical analyses of the data for two years was carried out using general linear model of the standard errors of the mean. The mean values for the respective parameter were the differences between the means of different stem differentiation treatments were compared by the least significant difference (LSD) tested at probability value p=0.05, wherever the results were significant, therefore a separate analysis of variance was conducted on each harvest period. For multiple comparisons, Duncan Multiple Range Test (DMRT) at P=0.05 was carried out according to DSAASTAT version 1.514 (Onofri 2007). The data reduction using the principal component analysis (PCA) according to XLSTAT version 2015.6.01 (Addinsoft, New York, USA) of yield, yield efficiency, growth traits and crown parameters for total harvest periods were also worked out.

RESULTS AND DISCUSSION

Vegetative growth traits

The data on growth characteristics of the emerging shoots under different treatments revealed that their vigour was significantly influenced· by the pruning severities (Table 1). Under high density planting, due to genetic factor, the cultivar Dashehari (vigorous) had the highest plant height, followed by Amrapali (semi-vigorous to dwarf) and Mallika (semi-vigorous) among different pruning treatments. Though, Amrapali had the highest canopy diameter, followed by Dashehari and Mallika. The effect of intensity of stem differentiation (T_4) was more pronounced on tree girth as

Table 1 Morphometric growth traits influenced by stem differentiation under high density mango orcharding

Treatment (T)	Mallika						Dashehari						Amrapali					
	Plant height (cm)	Canopy diameter (cm)		TG (cm)	ASEG (cm)	Leaf area (cm^2)	Plant height (cm)	Canopy diameter (cm)		TG (cm)	ASEG (cm)	Leaf area (cm^2)	Plant height (cm)	Canopy diameter (cm)		TG (cm)	ASEG (cm)	Leaf area (cm^2)
		E-W	N-S					E-W	N-S					E-W	N-S			
T_1	340.4	309.3	261.1	44.7	12.6	79.9	380.4	314.5	266.2	48.2	14.2	73.4	362.4	312.6	265.2	47.8	14.6	80.4
T_2	360.6	334.4	386.5	45.8	13.0	84.5	480.6	339.8	391.4	49.4	14.6	74.4	422.6	339.4	396.6	49.0	15.0	75.1
T_3	440.8	333.6	345.7	48.9	14.5	71.3	540.8	338.7	350.6	52.6	16.1	76.9	492.8	345.5	340.3	52.1	16.5	66.8
T_4	380.6	300.6	303.4	46.6	13.2	65.5	440.2	305.7	308.3	50.5	14.8	62.7	412.8	317.1	309.4	49.9	15.0	63.5
T_5	480.9	386.8	397.5	56.5	15.4	87.9	580.3	391.9	402.7	60.3	17.3	85.4	532.7	397.2	392.9	59.8	17.3	82.2
T_6	240.4	285.9	243.2	41.3	11.4	59.7	280.4	290.0	248.4	45.2	13.0	55.4	262.2	298.3	251.6	44.6	13.2	54.5
Mean	374.0	325.1	322.9	47.3	13.4	74.8	450.5	330.1	327.9	51.0	15.0	71.4	414.3	335.0	326.0	50.5	15.3	70.4
CV(%)	10.2	4.1	11.2	5.3	4.2	5.8	11.7	4.1	11.0	4.9	4.0	4.3	10.9	4.1	11.3	4.9	3.6	7.2
LSD (p=0.05)	65.2	22.5	61.6	4.3	0.9	7.4	89.7	22.9	61.5	4.3	1.0	5.2	76.7	23.6	62.7	4.3	0.9	8.7

E-W, East-west; N-S, north-south, TG, tree girth; ASG, annual shoot extension growth

compared to un-pruned trees. The trunk girth was highest in Amrapali followed by Mallika and Dashehari. Though the all 4 pruning intensities significantly affected trunk girth but maximum was noticed in T_4 pruned trees. The pruned trees produced more annual shoot extension growth of branches as compared to unpruned trees. Further, shoot pruning intensity significantly influenced on the number of days taken to first vegetative bud appearance with early bud appears in T_5 compared to control (data not shown). This attributed to relatively more nutrient available to vegetative bud and more light interception that induced early sprouting of vegetative buds in the shoots. Furthermore, all the shoot pruning treatments recorded early vegetative bud initiation compared to un-pruned control which might be due to the removal of apical dominance, release of buds from correlative inhibition and efficient transfer system. Thirupathi and Ghosh (2016) recorded that early shoot pruning after harvest facilitated more utilization of nutrients in shoot development rather than the utilization for wood formation during transport from root system to upper branches.

Sprouted shoots and canopy characteristics

The results inferred that the greater the stem differentiation, more were sprouted shoots per scaffold branch of emerged shoots near the cut. Dashehari cultivar showed increasing trend in the number of sprouted shoots per scaffold branch (both primary and secondary) followed by Amrapali and Mallika due very little growth in first year. Singh *et al.* (2009) reported that severe pruning caused sprouting of maximum number of shoots due to low shoot: root ratio compared to control. Oosthuyse and Jacobs (1996) recorded a higher rate of re-flowering in Sensation mango when the panicles (inflorescence) were removed at the site of apical bud compared to when pruning included the leaves clustered around the shoot apex. Further, they explained the presence of intercalation (cluster of axillary buds at the shoot apex) which in turn increased number of axillary buds developed in response to shoot pruning. TCSA, TCV and CA measurements were generally correlated and the data for growth dynamic of canopy parameters for period through eighteenth (2014) until twentieth (2016) cropping season following shoot pruning are presented in Table 2. However, severe pruning in T_3 and T_4 induced more TCSA, TCV and CA among the cultivars studied. TCV and CA irrespective of shoot differentiation for cultivars increased gradually with the increase of TCSA.

Flowering and fruiting behaviur

Shoot pruning intensities irrespective of cultivars registered late flower bud initiation and peak period of flowering, while early in control. The flowering in Dashehari was observed earliest (last week of February) followed by Mallika and Amrapali (first week of March) irrespective of the shoot differentiation treatments carried out. The flowering period of 20-25 days was observed in mango in north Indian Shiwalik foothills. However, different cultivars showed differential blooming period (Table 3). Interestingly, it was reported that severe pruning, registered a longer bloom period (22 days), while, shortest was in un-pruned trees (16 days). Singh *et al.* (2010) recorded that severity of pruning increased the blooming period and in 'on' year, it was longer than in 'off' year. Pruning increased the production of new shoots, due to endogenous auxins (apical dominance) which forced the induction of flowering, and enhanced the duration of blooming period with uniformity in 'on' year (Thirupathi and Ghosh 2016). Shoot pruning differentiation also stimulated the formation of vegetative shoots which allowed for the formation of more flower buds (Rahayu *et al.* 2013).

The data also revealed that different shoot pruning intensities significantly improved the panicle length and flowering shoot length in cultivars. Interestingly, the un-pruned (T_6) trees showed maximum length of panicles and

Table 2 Effect of stem differentiation on sprouted shoots and canopy characteristics of mango under high density orcharding

Treatment (T)	Mallika					Dashehari					Amrapali				
	Number of sprouted shoots per scaffold branch		TCSA (cm^2)	TCV (m^3)	CA (cm^2)	Number of sprouted shoots per scaffold branch		TCSA (cm^2)	TCV (m^3)	CA (cm^2)	Number of sprouted shoots per scaffold branch		TCSA (cm^2)	TCV (m^3)	CA (cm^2)
	Primary	Secondary				Primary	Secondary				Primary	Secondary			
T_1	6	18	159.1	180.5	25.5	7	18	185.0	234.5	26.5	7	13	181.9	219.8	26.2
T_2	6	13	167.0	200.7	40.8	5	24	194.3	311.3	42.0	6	14	191.2	269.3	42.5
T_3	7	15	190.4	279.7	36.2	6	16	220.3	397.1	37.3	6	18	216.1	355.0	36.9
T_4	6	16	172.9	219.3	28.6	9	21	203.0	297.9	29.6	8	14	198.2	272.8	30.8
T_5	7	17	254.2	407.4	48.3	10	26	289.5	560.0	49.6	8	24	284.7	505.6	49.0
T_6	3	7	135.8	108.8	22.0	4	10	162.7	152.0	22.8	5	10	158.4	138.4	23.7
Mean	5.8	14.3	179.9	232.7	33.6	6.8	19.2	209.1	325.5	34.6	6.7	15.5	205.1	293.5	34.9
CV (%)	10.1	14.9	10.8	19.9	13.6	25.9	19.9	10.1	18.9	13.4	14.6	8.8	10.3	19.1	13.9
LSD (P=0.05)	1.0	3.6	33.3	78.7	7.8	3.0	6.5	36.2	105.1	7.9	1.7	2.3	35.8	95.3	8.2

TCSA, Trunk cross-sectional area; TCV, tree canopy volume; CA, crown area

length of flowering shoots; while, the least was recorded in T_4 shoot pruned trees. The different shoot differentiation intensities significantly improved number of fruited panicles per shoot. T_5 pruned trees showed maximum number of fruited panicles compared to un-pruned control trees in all cultivars studied. Further, shoot pruning treatments had significantly increased the production of flowers which ensured an increase in fruit production through higher fruit set and retention within a panicle at pea stage in all the cultivars. The pruning intensities irrespective of the cultivars significantly reduced the fruit drop. The lowest fruit drop was recorded in T_5 and the highest in un-pruned trees. This resulted into higher production of mature fruits at harvest per panicle which in turn hastened the maturity earlier than the normal harvest in un-pruned trees. The finding draws the support from Chauhan *et al.* (2013) who also noticed favourable effect of pruning intensities to flower bud differentiation which had allowed maximum sunlight and chlorophyll content of leaves required for optimum photosynthesis compared to un-pruned trees.

Yield pattern, ABI and yield efficiency

Significant yield differences were also recorded between cultivars grafted in different shoot differentiation intensities throughout the investigation period. The best yield/tree over the 20th leaf harvest period (2014) through 2016 was recorded in Mallika followed by Amrapali and Dashehari (Table 4). Fruit yield, the most important aspect for fruit growers was significantly influenced by genotype and pruning (Singh *et al.* 2010). The effect of shoot pruning in mango on fruit yield potential, caused by diversion of mineral nutrients and water to productive branches in mango is well documented (Sharma and Singh 2006, Yeshitela *et al.* 2005, Waghmare and Joshi 2008). In Mallika, the highest fruit yield at harvest stage 49.4 kg/tree (2014); 46.8 kg/tree (2015) and 54.2 kg/tree (2016, 'on' year) was recorded in tip pruned frost affected twigs (terminal branches, T_5) followed by (T_3), whereas lowest fruit yield was recorded in un-pruned trees (T_6). High cumulative yield (CY) was recorded in Mallika followed by Amrapali and Dashehari in T_5 shoot differentiation treatment. Contrary to this, mango trees irrespective to shoot pruning with the lowest growth vigor (T_6) exhibited the lowest total yield. The CY (t/ha) in 20th leaf stage for Mallika was 12.4% and 29.2% higher than Amrapali and Dashehari, respectively. Until 20thyear after harvest, the varied ABI scores were observed for mango trees received different rates of shoot pruning. After 2016 cropping year, higher ABI values were observed for T_2 (Mallika) followed by T_1 (Dashehari), whereas, it was least in T_6 (Amrapali). The bearing surface of fruit plantations determines the yield efficiency (YE). YE as yield/TCA is valuable since TCA has been shown to be correlated to above ground weight of the tree. Thus, the ratio of yield to TCA is a fruit weight to total tree weight that reflects the efficiency of the entire weight of the tree to produce fruit. In the present study, the more vigorous mango trees were expected with reduced yield efficiency. YE affected by variable shoot differentiation for the leaf stage (2016) harvest year are shown in Fig 1. YEs compared to TCSA per unit slowly increased upon spacing, but rapidly decreased the yield per unit area. The YE per tree compared to TCV and LA kept practically the same rate and hardly changed if the changes in spacing (3×3m).

Fruit quality

The variable shoot pruning intensities showed significant effects on fruit physico-biochemical traits of the cultivars. Mallika exhibited maximum mean fruit dimension (length, width), fruit weight and fruit volume; whereas, these values were observed least in Amrapali. Mean fruit dimension,

Table 3 Flowering and fruiting behaviour of mango affected by pruning treatments in mango under high density orcharding

Treatment (T)	Mallika							Dashehari							Amrapali						
	Length of panicle (cm)	Length of flowering shoot (cm)	Number of panicles/ shoot	Fruited panicles (%)	Fruit set (%)	Fruit drop (%)	Fruit retentivo (%)	Length of panicle (cm)	Length of flowering shoot (cm)	Number of panicles/ shoot	Fruited panicles (%)	Fruit set (%)	Fruit drop (%)	Fruit retention (%)	Length of panicle (cm)	Length of flowering shoot (cm)	Number of panicles/ shoot	Fruited panicles (%)	Fruit set (%)	Fruit drop (%)	Fruit retention (%)
T_1	15.5	24.4	5.66	51.6	9.5	14.3	4.7	19.8	26.5	4.45	54.3	10.4	14.6	6.5	22.6	28.8	6.25	51.2	9.8	13.5	5.1
T_2	16.4	23.2	5.79	49.8	10.8	13.7	6.9	17.6	24.8	3.67	52.3	11.4	12.8	8.6	19.9	26.9	7.46	53.5	10.9	14.9	8.5
T_3	17.3	24.3	4.87	54.4	10.5	13.0	6.5	18.7	23.6	3.99	56.5	11.3	12.0	8.1	21.3	27.5	6.54	56.7	10.5	12.3	7.8
T_4	14.6	21.1	5.56	57.6	9.2	11.2	3.4	14.8	20.4	4.76	59.3	10.2	12.3	4.8	17.5	23.5	5.53	54.4	9.8	11.7	4.4
T_5	18.3	25.5	4.75	66.8	11.1	10.2	7.9	22.9	27.7	4.88	65.6	11.7	10.9	9.1	22.5	28.3	6.64	68.3	11.3	10.9	9.4
T_6	20.3	26.2	3.54	46.3	6.3	17.4	1.2	20.2	27.9	3.76	44.8	8.1	16.4	2.2	24.8	29.6	4.55	42.5	8.6	15.9	1.9
Mean	17.1	24.1	5.02	54.4	9.6	13.3	5.1	19.0	25.2	4.25	55.4	10.5	13.2	6.6	21.4	27.4	6.16	54.4	10.2	13.2	6.2
C V (%)	5.6	4.4	7.52	8.89	9.1	13.6	17.8	9.9	8.2	9.18	8.70	6.1	9.5	14.5	7.9	4.9	10.57	10.72	4.8	10.4	18.9
LSD (P=0.05)	1.6	1.8	0.64	8.24	1.5	3.1	1.5	3.2	3.5	0.66	8.22	1.1	2.1	1.6	2.9	2.3	1.10	9.94	0.8	2.3	1.9

Table 4 Yield pattern and alternate bearing index influenced by shoot differentiation pruning in mango at the end of 20th harvest season.

Treatment (T)	Mallika								Dashehari								Amrapali							
	Yield (kg/tree)				Yield (t/ha)	CY (kg/tree)	CY (t/ha)	ABI	Yield (kg/tree)				Yield (t/ha)	CY (kg/tree)	CY (t/ha)	ABI	Yield (kg/tree)				Yield (t/ha)	CY (kg/tree)	CY (t/ha)	ABI
	2014	2015	2016	Mean					2014	2015	2016	Mean					2014	2015	2016	Mean				
T_1	44.0^{d}	42.9^{c}	50.8^{c}	45.9	51.0^{c}	86.9^{f}	96.6^{f}	0.155^{a}	32.3^{d}	25.7^{c}	40.9^{c}	33.0	36.6^{c}	58.0^{f}	64.4^{f}	0.266^{a}	40.1^{c}	39.4^{e}	42.6^{d}	40.7	45.2^{c}	79.5^{d}	88.3^{d}	0.062^{b}
T_2	44.9^{c}	43.2^{b}	52.3^{b}	46.8	52.0^{b}	140.4^{b}	156.0^{b}	0.165^{a}	34.6^{c}	26.6^{b}	42.4^{b}	34.5	38.4^{b}	103.6^{b}	115.1^{b}	0.225^{a}	41.0^{b}	39.7^{d}	43.4^{b}	41.4	46.0^{b}	124.1^{b}	137.9^{b}	0.059^{b}
T_3	46.4^{b}	42.1^{d}	49.5^{d}	46.0	51.1^{c}	138.0^{c}	153.3^{c}	0.067^{a}	35.8^{b}	23.8^{e}	39.6^{d}	33.1	36.7^{c}	99.2^{c}	110.2^{c}	0.106^{a}	38.2^{d}	42.8^{b}	42.9^{c}	41.3	45.9^{b}	123.9^{b}	137.7^{b}	0.123^{ab}
T_4	43.9^{d}	40.2^{e}	43.7^{e}	42.6	47.3^{d}	127.8^{d}	142.0^{d}	-0.005^{a}	32.4^{d}	24.2^{d}	35.7^{e}	30.8	34.2^{d}	92.3^{d}	102.6^{d}	0.102^{a}	33.6^{e}	41.8^{c}	37.5^{e}	37.6	41.8^{d}	112.9^{c}	125.4^{c}	0.116^{ab}
T_5	49.4^{a}	46.8^{a}	54.2^{a}	50.1	55.7^{a}	150.4^{a}	167.1^{a}	0.097^{a}	37.7^{a}	28.5^{a}	44.3^{a}	36.8	40.9^{a}	110.5^{a}	122.8^{a}	0.175^{a}	46.6^{a}	43.2^{a}	47.1^{a}	45.6	50.7^{a}	136.9^{a}	152.1^{a}	0.011^{b}
T_6	32.6^{e}	31.9^{f}	34.2^{f}	32.9	36.6^{f}	98.7^{e}	109.7^{e}	0.049^{a}	22.9^{e}	12.9^{f}	25.8^{f}	20.5	22.8^{e}	61.6^{e}	68.4^{e}	0.127^{a}	22.6^{f}	21.3^{f}	29.6^{f}	24.5	27.2^{e}	73.5^{e}	81.7^{e}	0.310^{a}
Mean	43.5	41.2	47.5		49.0	123.7	137.5	0.088	32.6	23.6	38.1		34.9	87.5	97.3	0.167	37.0	38.0	40.5		42.8	108.5	120.5	0.114

CY, Cumulative yield; ABI, alternate bearing index; Mean followed by same letter within columns are not significant according to Tukey's HSD method (P=0.05)

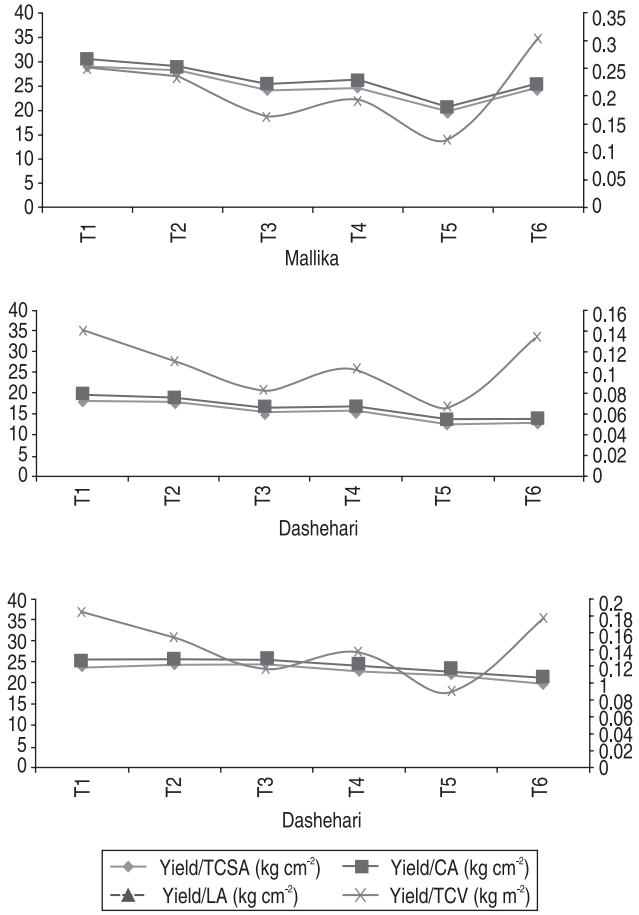

Fig 1 Yield efficiency for mango cultivars in fifth at 20th harvest season.

weight and volume was significantly influenced by different shoot pruning treatments and was recorded highest in T_5 shoots pruned followed by T_4, T_2 shoot pruned trees, while, the lowest was recorded in T_6. The reason ascribed to lesser availability of nutrients for fruit growth and development (Thirupathi and Ghosh 2016). Mean TSS (21.8ºB) and total sugars were highest Amrapali followed by Dashehari and Mallika. Minimum fruit pH and acidity content was recorded in T_5 shoot pruned trees of Amrapali followed by Dashehari and Mallika, whereas, the TSS and acidity ratio were observed in the order of Dashehari>Amrapali>Mallika. T_5 treatment increased TSS and reducing sugar in fruits. The increase in TSS and total sugar content was observed with increasing pruning intensities (Hossani and Razaee 2007). Improved soluble solids and total sugars are correlated with increase light intensity (Kaundal *et al.* 2002). The increased rate of photosynthesis due to more light penetration into interior tree canopy increased TSS of shoot pruned trees. The decrease in acidity is attributed to deposition of higher quantum of acid that is synthesized in leaves during the fruit development (Somkuwar and Ramteke 2007, Porika *et al.* 2015).

Foliar nutrient composition: The DOP indexing

Variable stem differentiation treatments had a significant effect on the amount of leaf nutrient macro-, meso- and

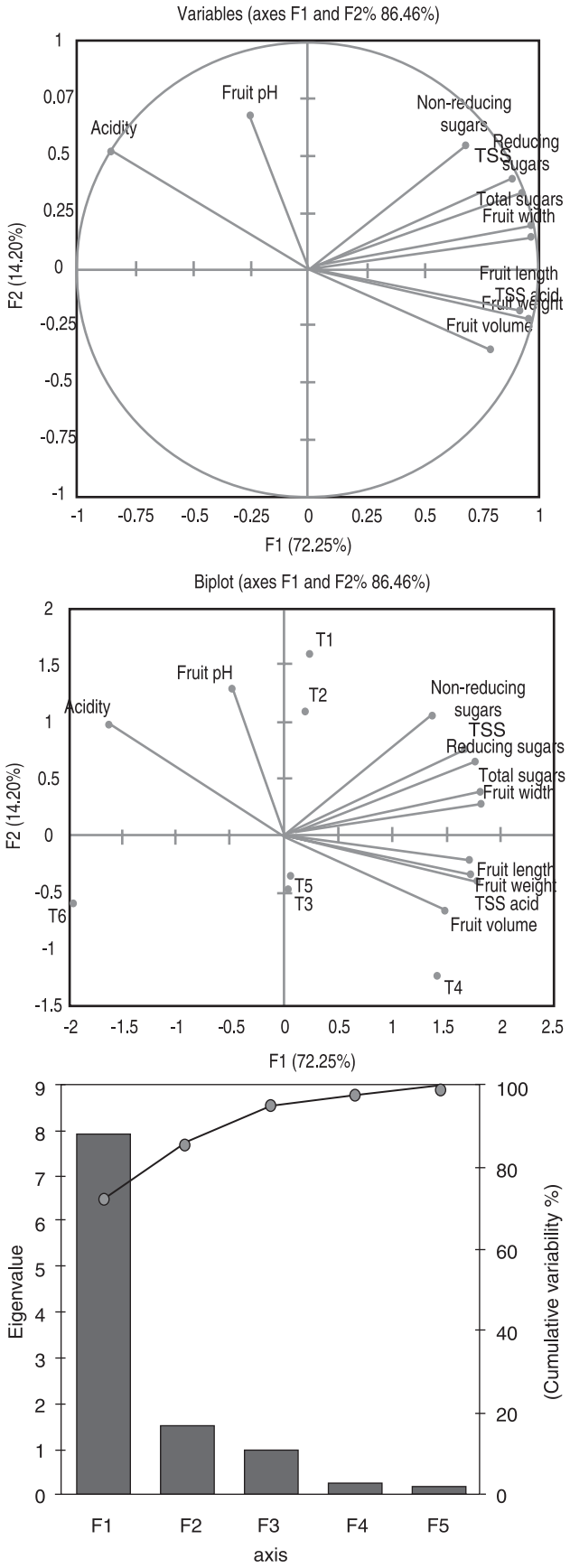

Fig 2 PCA-Correlation biplots (A-B) and Scree plot (C) of among fruit quality traits in mango cultivars at different shoot differentiation pruning treatments.

Table 5 The DOP index and ΣDOP determined from mango leaf nutrients at various pruning treatments in mango from full panicle emergence to harvest.

Cultivar	Treatment (T)	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	ΣDOP
	T_1	+86.1	+182	+31.7	-17.4	+177.3	-8.2^{d}	-6.3	+0.6	+4.3	513.9^{c}
	T_2	+83.6	+164	+28.7	-16.7	+179.5	-4	+0.6	+10.2	+7	494.3^{e}
	T_3	+79.5	+162	+30.6	-19.8	+206.8	-8.8	-6.8	+2.2	+1	517.5^{b}
Mallika	T_4	+76.2	+198	+25.8	-19.8	+170.5	-8.7	-1.1	+5.7	-2.9	508.7^{d}
	T_5	+89.3	+216	+30.9	-15.1	+215.9	-8.2	+5.7	+15.6	+8	604.7^{a}
	T_6	+63.1	+138	+19.2	-27.5	+145.5	-20.5	-15.9	-5.7	-16.4	451.8^{f}
	Mean										515.2^{A}
	T_1	+72.1	+188	+29.2	-22.1	+168.2	-1.5	-10.2	-6.7	+1.2	499.2^{c}
	T_2	+67.2	+160	+26.4	-19.8	+150	+1.2	-5.7	-1.9	-0.4	432.6^{f}
	T_3	+75.4	+178	+30.9	-20.9	+184.1	-2.3	-8.5	-4.8	-3	507.9^{b}
Dashehari	T_4	+68	+186	+18.3	-18.6	+179.5	-5.8	-8	-1	-2.2	487.4^{d}
	T_5	+81.1	+210	+29.8	-17.4	+177.3	-1.6	+2.8	+10.8	+4.5	535.3^{a}
	T_6	+59	+148	+22.5	-31	+129.5	-13.7	-22.2	-16.2	-14.2	456.3^{e}
	Mean										486.5^{C}
	T_1	+79.5	+186	+30.6	-19.8	+172.7	-4.8	-8	-2.9	+2.8	507.1^{c}
	T_2	+75.4	+162	+27.5	-18.2	+165.9	-1.4	-2.3	+4.1	+3.3	460.1^{e}
	T_3	+77.9	+170	+30.8	-20.2	+195.5	-5.6	-7.4	-1.3	-1	509.7^{b}
Amrapali	T_4	+72.1	+192	+22.1	-19	+175	-7.2	-4.5	+2.5	-2.5	496.9^{d}
	T_5	+85.2	+214	+30.4	-16.3	+197.7	-4.9	+4.5	+13.3	+6.3	572.6^{a}
	T_6	+61.5	+144	+20.9	-29.1	+138.6	-17.1	-18.8	-10.8	-15.3	456.1^{f}
	Mean										500.4^{B}

Leaf composition standards for mango based on non-fruiting terminals sampled (Samra *et al*. 1978, *Kumar et al.* 2013); sign (−) indicates deficiency level, sign (+) indicates excessive level; Mean followed by same letter within columns among ΣDOP indexes within each pruning treatment and the cultivar are not significant according to Tukey's HSD method (P=0.05).

micronutrient concentration of the trees. Small but least significant differences were observed among cultivars for leaf N, P, K, Ca, Mg and micronutrient concentration irrespective of shoot pruning. Nitrogen is the main growth manipulating nutrient. Singh *et al.* (2010) observed that the period of vegetative dormancy before flowering should be considered as a period of low nitrogen requirement, as simulative vegetative growth would reduce flowering and productivity. T_5 treatment resulted in significant differences among different cultivars for leaf N, P, K, Ca, Mg, Fe, Cu, Zn and Mn concentration compared to un-pruned shoots, due to more number of flowered shoots emergence in Amrapali than Dashehari (Singh *et al*. 2010). The results of Devi and Tyagi (1991) also supported these findings.

DOP indexing showed close agreement to diagnose N, P, K, Mg, Fe, Cu, Zn and Mn excesses, whereas, it was in deficiencies for leaf Ca content among different cultivars studied (Table 5).The $DOP_{N, P, K, Mg, Cu, Zn}$ was positive and $DOP_{Ca, Fe}$ was negative in Mallika mango trees regardless of shoot differentiation treatments. For $DOP_{Cu, Mn}$ level, the trees pruned under T_4 had negative DOP value. Nachtigall and Dechen (2006) revealed that leaf N, P, K, Mg was in excessive range, when leaf Ca concentration was deficient, probably a consequence of lower K competition, which is universal trait of leaf Mg. The negative DOP_{Ca} attributed to low mobility and low availability in soil, while, negative $DOP_{Fe, Mn}$ indicated the tendency of these nutrients deficiency. Decreased availability in the soil due to fixation by clay particles reported by Saykhul *et al.* (2014). Significant differences between cultivars, for nutritional balance (ΣDOP) were obtained. Larger the ΣDOP, the greater was the intensity of imbalance among nutrients (Montañés *et al.* 1993, Kumar *et al.* 2017)). The cultivar, Dashehari exhibited better balanced nutritional value, followed Amrapali compared to Mallika, which confirmed the better adaptation of Dashehari to heavy clay soils resulted in higher morphometric vigourness than Amrapali and Mallika.

PCA studies for morphometric growth traits, yield and fruit quality

PCA analysis transformed mutually correlated morphometric and fruit quality characteristics (variables) in principal components (PCs), which are other-wise not correlated. The data reduction technique of phenological traits of mango cultivars to evaluate the differences induced within shoot pruning treatments was performed. The graphical interpretation (*Scree,* PCA biplots) with the original factors/variables drawn as *Eigen vectors* that summarize the correlation between the variable and both

illustrated axes of pomological traits (plant height, fruit yield, cumulative fruit yield, tree girth, ASEG, leaf area), crown parameters (TCSA, TCV, CA) and YEs (yield/TCSA, yield/TCV, yield/CA, yield/LA (Table 6). PCA studies for growth and yield indicated only four first components, accounted for maximum of the total variance. PCA for identified for four factors based on *Eigen value* (>1) and explained 62.72% in first (prin1), 83.11% in second (prin2), 93.48% in third (prin3) and 99.56% in fourth (prin4) of the cumulative variance, respectively. The prin1, which accounted for about 62.72% of the variability, was strongly associated with plant height, tree girth, ASEG, leaf area, TCSA, TCV, CA and cumulative fruit yield among mango cultivars irrespective of shoot pruning treatments applied. The sign of the factor loading indicates the direction of the relationship between the component and the variable. Therefore, the selection may be done according to prin1, and it was helpful for a good orchard management practices to improve productivity traits. prin2, which accounted for about 20.38% of the total variation, included as fruit yield and YEs (consisted of yield/TCSA, yield/CA and yield/LA). Similarly, the minimum data set suggested for fruit quality attributes by PCA is fruit length, fruit breadth, fruit weight, fruit firmness, total soluble solids, acidity, TSS: acid ratio, reducing sugars, non-reducing sugars, total sugars, fruit colouration and ascorbic acid content (Fig 2). Highly weighted variables (factor loadings >0.40) among different PCs were selected (Wander and Bolero 1999, Kumar *et al.* 2016). *Scree* plot showed break point that comes after prin4 component. prin4 which explained 97.9% of the cumulative variance was considered. The PCA-F1 had the highest positive loadings from all traits except fruit pH and acidity, where, it was negative. Similarly, the *Scree* plot is done by constructing PCA biplots with the original factors/variables drawn as *Eigen vectors* that summarize the correlation between the variable and both illustrated axes of phenological traits.

Table 6 PCA (Pearson, n) and factor loadings in agro-morphological traits, fruit yield and yield efficiency in mango cultivars at different pruning intensities.

Parameter	Principal component			
	prin1	prin2	prin3	prin4
Eigen value	8.15	2.65	1.35	0.79
Variability (%)	62.72	20.38	10.38	6.07
Cumulative variance (%)	62.72	83.11	93.48	99.56
Factor loadings				
Agro-morphological traits	F1	F2	F3	F4
Plant height	0.97	-0.20	0.03	-0.02
Tree girth	0.97	0.13	0.04	0.22
Annual shoot extension growth	0.98	-0.05	0.00	0.13
Leaf area	0.69	-0.20	0.66	0.21
Fruit yield	-0.23	0.97	0.08	0.05
Cumulative fruit yield	0.90	-0.01	-0.04	-0.42
Crown parameters				
TCSA	0.99	0.08	0.04	0.14
TCV	0.95	0.17	0.04	0.23
CA	0.91	0.11	0.32	-0.23
Yield efficiencies				
Yield/TCSA	-0.30	-0.81	0.45	-0.22
Yield/TCV	-0.76	0.09	0.63	-0.11
Yield/CA	-0.55	-0.64	-0.02	0.53
Yield/LA	0.54	-0.71	-0.43	-0.16
Factor scores				
Treatment (T)	*F1*	*F2*	*F3*	*F4*
T_1	-2.37	-1.68	1.15	1.33
T_2	0.05	-0.52	1.54	-1.53
T_3	1.81	-0.79	-0.83	-0.31
T_4	4.75	1.78	0.44	0.72
T_5	-0.04	-1.42	-1.81	-0.12
T_6	-4.18	2.64	-0.48	-0.09

Mean (factor score) followed by same letter within columns are not significant according to Tukey's HSD method (P=0.05); F1, factor-1; F2, factor-2; F3, factor-3; F4, factor-4; prin1, Principal Component-1; prin2, Principal Component-2; prin3, Principal Component-3; prin4, Principal Component-4; TCSA, trunk cross-sectional area; TCV, tree canopy volume; CA, crown area; LA, leaf area.

Different shoot differentiation pruning treatments significantly affected vegetative growth measurements, flowering and generative parameters variably in all the three cultivars of mango. Tip pruning of frost affected twigs (terminal branches) stem differentiation among all the cultivars produced significantly improved yield and yield efficiency compared to un-pruned (control) which help in massive rejuvenation of frost affected non-bearing mango orchards.

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