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Effect of planting densities on productivity of different cultivars in apple (*Malus* × *domestica*)

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ABSTRACT

Relationship between crop density and yield efficiency was studied to assess the influence of fruit number on yield of cultivars under different planting densities in apple (*Malus* × *domestica* Borkh). Under 4.0 × 4.0 m spacing, crop density ranged between 0.38 in cv Red Fuji to 2.11 in American Apirogue with an average of 1.20 and under 2.5 × 2.5 m spacing, crop density ranged from 0.44 in cv Red Fuji to 1.69 in Vance Delicious with an average of 1.22. Maximum fruit weight (197 g) was observed in cv Red Delicious and minimum fruit weight (120 g) was observed in American Apirogue under 4.0 × 4.0 m. Yield efficiency under 4.0 × 4.0 m spacing ranged from 0.06 kg/cm^2 for Red Fuji to 0.31 kg/cm^2 for Red Delicious with an average of 0.19 kg/cm^2. Maximum yield efficiency (0.28 kg/cm^2) was observed in cv Mollies Delicious and Vance Delicious but minimum (0.07 kg/cm^2) in Red Fuji under 2.5 × 2.5 m spacing. Thus crop load influences both fruit size and yield efficiency of apple varieties differently under two densities.

Key words: Apple, Cropping density, Fruit load, Yield efficiency

The apple (*Malus* × *domestica* Borkh) is one of the most important temperate fruit crop and its productivity is dependent on many production factors. The rootstock and scion are the important factors to decide the productivity besides planting density in apple. In addition, flower bud formation, pollination, fruit set, spur density, fruit number and fruit size also contribute in production of quality fruit. The productivity of apple in India is less than other countries due to non adoption of advanced technologies by the farmers. Lakso and Wünsche (2000) reported that fruit yield is a function of two components, i.e. fruit number and fruit size. Fruit number, as the primary factor, is mainly affected by flower bud formation and final fruit set. The size of a tree is usually expressed as trunk cross-sectional area (TCSA). It is the most common surrogate measurement to determine the tree size and, indirectly, the capacity of a tree to produce fruits (Jimenez and Diaz 2004, Wright *et al.* 2006). When the number of fruits per unit area of the cross section of a trunk (Lombard *et al*. 1988) or per volume of a tree canopy (Wright *et al.* 2006) is counted and crop density parameter is obtained. The studies by Bergh (1990), Marini *et al*. (2002) and Treder (2008) indicate that the number of fruits per TCA may predict the proper crop load in the most satisfactory way. Crop load, defined as the number of fruits/tree, has a significant impact on both fruit quality and tree physiology (Wünsche *et al*. 2005, Treder *et al*. 2010). Crop load is often expressed in terms of number of fruits/trunk cross sectional area (TCSA) and named crop density (Lombard *et al*. 1988). The studies by Webb *et al*. (1980), Bergh (1990), Marini *et al*. (2002) indicate that the number of fruits/TCA may predict the proper crop load in the most satisfactory way. Fruit size is different for each cultivar, although it is also dependent on number of fruits left on the tree, climate and cultural practices. Therefore, correlation of crop density with fruit size and finally with yield efficiency is important parameter for predicting the yield potential of the variety.

Apple growers are under increasing pressure to enhance fruit size to satisfy consumer demands, but profitability in an apple orchard also depends on optimal yield and high fruit quality. The fruits act as a strong carbohydrate sink and high crop loads can constrain vegetative growth, reducing the interception of light and the future productivity of the orchard (Yuri *et al*. 2011). Information on crop load manipulation and fruit quality are of particular importance to growers in order to optimize the number of fruits/tree to achieve the desired fruit qualities (Treder 2008, Meland 2009). Planting density also has impact on crop loads and yield of the apple tree. Both crop load and yield efficiency

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of the tree are dependent on tree trunk cross section area. Trunk cross-sectional area of tree fruit crops has been found useful index for estimation of growth, yield and quality of fruits (Kumar *et al*. 2008). The ability to develop a relationship between trunk cross sectional area, which directly relates to the tree size and yield contributing parameters, will improve our understanding of predicting the yield of different apple varieties irrespective of the age of plant.

Keeping in view the role of crop density, the study was carried out to quantify the interrelationship between the CD (number of fruit produced per unit of TCSA) and yield efficiencies of different apple varieties as affected by planting densities to identify the varieties suitable for different planting densities.

MATERIALS AND METHODS

Present experiment was carried out during 2013-14, using 10 apple cultivars namely, Red Delicious, American Apirogue, Red Chief, Silver Spur, Starkrimson, Mollies Delicious, Golden Delicious, Vance Delicious, Red Fuji and Oregon Spur at ICAR-Central Institute of Temperate Horticulture, Srinagar (J and K), India. The experiment was carried out on six-year-old apple cultivars grafted on MM-106 rootstock. These varieties were planted at two different spacings (2.5 × 2.5 m and 4.0 × 4.0 m). Evaluation was carried out to study the relationship between crop density and yield efficiency for identification of suitable planting density for different cultivars. For each cultivar, 10 plants growing in a single row were selected on the basis of uniform growth habit. At the beginning of the vegetative growth season, the trunk cross-sectional area (TCSA) of every plant was measured 15 cm above the scion-graft union. The trunk cross-sectional area (TCSA) was calculated by using standard formula (TCSA= $Girth^2/4\pi$). Crop loads were calculated as number of fruits/unit TCSA (Lamb 1972, Lombard *et al*. 1988). Fruits were counted, weighed and measured at the time of harvest which varies for different varieties. Yield efficiency was calculated as total weight of fruit per unit TCSA (kg/cm^2 of TCSA). The fruit yield/tree was recorded and mean fruit weight was calculated as an average from ten fruits in each variety, collected from entire tree canopies. Correlation analysis was performed in order to determine the relationships between crop load and yield efficiency among the varieties under two planting densities. Results were elaborated statistically by analysis of variance and differences between means were evaluated using Duncan's multiple range test at $P = 0.05$ (Duncan 1955).

RESULTS AND DISCUSSION

Estimation of yield and yield attributing characteristics of apple varieties under different densities was calculated using TCSA. TCSA is used regularly to compare vigor (TCSA/ha), efficiency (kg/TCSA), crop load (number of fruits/TCSA) etc (Barritt *et al*. 1997, Caruso *et al*. 1999). Plant density influences yield, since it affects the amount of light received by the tree and light interception by the tree has direct correlation with TCSA (Robinson and Lakso 1991). In present study, under 4.0 × 4.0 m spacing, crop density (CD) ranged between 0.38 number of fruits/ cm^2 of TCSA in variety Red Fuji to 2.11 in American Apirogue with an average of 1.20 while under 2.5 × 2.5 m spacing, CD ranges from 0.44 in variety Red Fuji to 1.69 in Vance Delicious with an average of 1.22. Varietal variation in crop density was observed but overall average crop density between two spacing for all varieties was similar (1.20). Under 4.0 × 4.0 m spacing, maximum fruit weight (197 g) was observed in variety Red Delicious and minimum fruit weight (120 g) in American Apirogue and under 2.5 × 2.5 m spacing, fruit weight ranged from 120 g in American Apirogue to 190 g in Red Delicious. Better fruit size was found under 4.0 × 4.0 m spacing for all varieties except American Apirogue (120 g) and Starkrimson (130 g) which showed similar sized fruits under both the spacings. Crop density was negatively correlated (-0.27) with fruit size under 4.0 × 4.0 m spacing but showed weak positive correlation (0.22) under 2.5 × 2.5 m spacing. Heavy loading did not influence the fruit size significantly, although varietal influence of crop load on fruit size was observed (Table 1) but overall number of fruits was positively correlated with fruit size with respective correlation of 0.19 and 0.13 under 4.0 × 4.0 m and 2.5 × 2.5 m spacings. A low crop load resulted in a larger growth rate than a high crop load, due to less competition for available photo-assimilates. If the demand for photo-assimilates exceeded the amount available early in the season, due to a heavy crop load, this leads to decreased fruit growth (Lakso and Corelli Grappadelli 1993). The effects of crop load on fruit growth and on final fruit weight are well documented (Forshey and Elfing 1989, Palmer *et al*. 1997). Fruit weight at harvest was negatively correlated with crop load, and fruit weight was greatest when there was minimum competition between fruit (Palmer *et al*. 1997). Since in our experiment the initial crop load was not so heavy with 235 as maximum number of fruits/ plant and with highest crop density of 2.11 which does not bring any competition between fruits. Therefore, the size of fruit increased without any competition. Since the experiment was conducted on six year old trees, the trend may change with the age of trees. Balanced fruit and vegetative growth results in an increased availability of assimilates and potentially higher fruit quality at harvest (Palmer *et al*. 1991). Too intensive thinning may reduce both yield and effectiveness of photosynthesis, which means that the productive potential of trees is not realized (Giuliani *et al*. 1997). An important factor influencing the size of fruit at the predetermined level of CD is the type of rootstock, variety and planting density used (White and Tustin 2002, Marini *et al*. 2002). The key role in obtaining desired fruit size is played by the individual genetic properties of the plants.

Yield efficiency allows for a direct comparison of trees of varying sizes and can be used for estimating the yield potential of different varieties of apple grown under different planting densities. In the present study, yield efficiency

Table 1 Impact of planting density on yield and yield related parameters in apple

Cultivar	TCSA (cm^2)		No. of fruits/tree		Crop density (fruits/ cm^2 TCSA)		Fruit weight (g)		Yield (Kg/tree)		Yield (tonnes/ha)		Yield efficiency (Kg/cm^2)	
	4.0×4.0m	2.5×2.5m	4.0×4.0m	2.5×2.5m	4.0×4.0 m	2.5×2.5m	4.0×4.0m	2.5×2.5m	4.0×4.0m	2.5×2.5m	4.0×4.0m	2.5×2.5m	4.0×4.0m	2.5×2.5m
Red Chief	148.46^{C}	135.27^{A}	191^{D}	140^{B}	1.28^{E}	1.01^{F}	165.6^{E}	160 ^{E}	31.62^{D}	22.4^{B}	19.76^{C}	35.84^{C}	0.21 ^{D}	0.16 ^{D}
Oregan Spur	148.46^{C}	104.98^{B}	215^{B}	150A	1.44^{D}	1.48^{C}	186.5^{B}	180^{B}	40.1^{B}	27^{A}	25.06^{B}	43.2^{A}	0.27 ^{B}	0.27 ^{A}
Red Fuji	169.4^{B}	135.27^{A}	65^{F}	60^{G}	0.38^{J}	0.44^{H}	153.5 ^{F}	148^{F}	9.97 ^{H}	8.8^{E}	6.23^{F}	14.20^{G}	0.06 ^{I}	0.07 ^{F}
Vance Delicious	141.79^{D}	88.61^{C}	135^{E}	150^{A}	0.95^{H}	1.69^{A}	170.5^{D}	168^{D}	23.02^{F}	25.2^{A}	14.39^{D}	40.32^{B}	0.16 ^{F}	0.28 ^{A}
Silver Spur	128.91^{E}	104.98^{B}	132^{E}	90^{D}	1.02^{G}	0.85^{G}	140.5 ^{G}	140^{G}	18.44^{G}	12.6^{D}	11.59^{E}	20.16^{F}	0.14 ^{GH}	0.12 ^{E}
Golden Delicious	176.68^{A}	104.98^{B}	192^{D}	130^{C}	1.08^{F}	1.23^{D}	180 ^{C}	175^{C}	34.56^{C}	22.75^{B}	21.6^{C}	36.4^{C}	0.19 ^{DE}	0.22 ^{B}
American Apirogue	99.38^{F}	88.65^{C}	210^{C}	140^{B}	2.11^{A}	1.57^{B}	120 ^{I}	120^{I}	25.2^{E}	16.8^{C}	15.75^{D}	26.8^{D}	0.25 ^{BC}	0.19 ^{C}
Starkrimson	88.65^{G}	64.49^{E}	135^{E}	75^{F}	1.52^{C}	1.16^{E}	130 ^{H}	130^{H}	17.55^{G}	9.75^{E}	10.96^{E}	15.6^{G}	0.20 ^{D}	0.15 ^{D}
Mollies Delicious	88.65^{G}	55.9^{F}	62^{F}	90^{D}	0.69^{I}	1.6^{B}	180 ^{C}	178^{B}	11.16^{H}	16.02^{C}	6.97^{F}	25.6^{DE}	0.12 ^{G}	0.28 ^{A}
Red Delicious	148.46^{C}	69.01^{D}	235^{A}	80^{E}	1.58^{B}	1.15^{F}	197 ^{A}	190^{A}	46.29^{A}	15.2^{C}	28.93^{A}	24.32^{E}	0.31^{A}	0.22 ^{B}

Means followed by the same letter within the columns are not significantly different (P=0.05) using Duncan's multiple range test.

under 4.0 × 4.0 m spacing ranged from 0.06 kg/cm^2 for Red Fuji to 0.31 kg/cm^2 for Red Delicious with an average of 0.19 kg/cm^2. Maximum yield efficiency (0.28 kg/cm^2) was observed in variety Mollies Delicious and Vance Delicious but minimum (0.07 kg/cm^2) in Red Fuji under 2.5 x 2.5 m spacing. Therefore, yield efficiency was found higher under 4.0 × 4.0 m spacing but the number of plants under this density were 625/ha as compared to 1 600 plants/ha under 2.5 × 2.5 m spacing. Average total yield/ha was found higher (28.2 tonnes/ha) under 2.5 × 2.5 m spacing as compared to 4.0 × 4.0 m spacing (16.2 tonnes/ha). Therefore although individual plants perform better with higher yield potential under low density plantation but overall productivity is higher under high density plantation. Relationship between crop density and yield efficiency was studied in order to assess the influence of fruit number on total yield of the variety under different planting densities. A strong positive correlation was observed between crop density and yield efficiency under 4.0 × 4.0 m spacing (0.85) and 2.5 × 2.5 m spacing (0.90). Varieties Red Delicious, American Apirogue, Red Chief, Silver Spur and Starkrimson performed better under 4.0 × 4.0 m spacing as depicted by their higher yield efficiencies under this spacing. Varieties Mollies Delicious, Golden Delicious, Vance Delicious, and Red Fuji showed better performance under 2.5 × 2.5 m spacing. Variety Oregon Spur performed equally well under both the spacings with yield efficiency of 0.27. Fruit size and yield efficiency were affected by crop load, although there were differences between cultivars. Most studies on apples have found negative correlation between mean fruit weight and crop load (Elfving and Schechter 1993, Embree *et al*. 2007, Wright *et al*. 2006). This is due to the fact that fruit size is mainly determined by the number of cells per fruit and their subsequent enlargement (Harada *et al*. 2005) and both factors are affected by the competition for carbon between developing fruits as crop load increases (Ho 1992).

Each variety grown under particular planting density should have optimum crop load which maximizes fruit yield and at the same time avoids detrimental effects on fruit quality, the following year's yield, or tree vigor (Link 2000). The optimal crop load for each cultivar need to be standardized under different densities and factors other than crop load influencing the fruit size, fruit color or yield of small- and middle-sized fruits (Link 2000, Treder 2008, Volz 1988, Wrigth *et al*. 2006) need to be standardized. Study on factors like pruning intensity, initial fruit set, previous crop load of the trees, mineral nutrition, time of fruit thinning, flower bud quality, and age of the trees will provide complete information on yield potential of a variety under particular planting density.

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