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Research article

Analysis of soil and tree productivity under high density planting system in mango cv. Dashehari (*Mangifera indica* L.)

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Abstract: Farmers have no alternative but to adopt high-density planting for enhancing fruit productivity level and profitability with the shrinking land resources and smaller land holding sizes. The highest yield of 16 t ha^{-1} followed by 10.0 t ha^{-1} and the least of 5.5 t ha^{-1} was recorded from 400, 267 and 100 trees ha^{-1}, respectively from 19 yrs old Dashehari mango orchard in sandy loam soils at research farm of ICAR-CISH, Rehmankhera, Lucknow. Planting density systems (1600, 800, 400, 266, 178 and 100 trees ha^{-1}) also impacted soil properties. Water holding capacity varied between 16.6 to 26.1 % across systems while porosity ranged from 46.2–71.5 %. Likewise, bulk density and particle density had values of 1.2 to1.7 and 2.2 to 2.9 g cm^{-3} respectively. The mean soil organic carbon content was 0.38%, pH of 7.2, available N, P, K was 66.92, 13.91 and 77.85 mg kg^{-1} respectively. Soil and leaf micronutrients analyzed across six different density systems showed wide variations and indicated the need for optimum nutrient management. Significant and positive correlations were recorded between soil organic carbon with other soil properties. The study revealed that medium density system (400 trees ha^{-1}) is to be practiced at farmers' field.

Keywords: High-density system - Traditional planting - Yield - Soil properties - Statistical correlation.

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INTRODUCTION

With the fast growth of urban development, industrial development, housing projects and other related land-based projects, availability of farming land is shrinking. Farmers are searching for an alternative system of planting fruit crops apart from traditional planting system in order to maintain their productivity level and earning. In this backdrop, high-density planting system (HDP) emerged as alternative system of plantations for sustaining the fruit production level (Singh *et al*. 2007). In general, traditional cultivation of mango (10.0 × 10.0 m spacing) can accommodate 100 trees ha^{-1} while the HDP aims at accommodating 1600, 800, 400, 266 and 178 trees ha^{-1}. The yield potential of these orchards was targeted for at least 20 t ha^{-1} based on soil and tree management system. Meland (2005) recorded the highest cumulative yield after 9 yrs of planting in high density system of 5000 trees ha^{-1}. Even, Zaman & Schuman (2006) also opined that in order to obtain desirable fruit yield, site-specific nutrient management based on soil properties and tree performance should be the top priority. Distribution of soil micronutrients should also be considered for quality production (Nagendran & Angayarkanni 2010, Sharma *et al*. 2011, Mishra 2014). Singh *et al*. (2017) recorded the highest yield of 22.72 and 23.36 kg tree^{-1} from a 13 years old Amrapali mango in high-density system (2.5 × 2.5 m) under different integrated nutrient management system.

For any production level, soil plays immense role for not only maintaining a satisfactory level of yield but also to sustain it for a long-term basis. The key component being its physical, chemical and biological parts that contribute significantly towards soil quality guarding the productivity level. Under normal/traditional system, management of soil properties is crucial, however, in case of high-density systems, role of soil required more emphasis as nutrient mining is obvious. Adak *et al*. (2015) observed that compaction in lower depth soils

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increased the bulk density and lowers porosity across six plantation systems. Water holding capacity was higher in the system where less number of trees were accommodated than 1600 and 800 trees ha^{-1}. Singha *et al.* (2016) based on a study on 20 yrs old Guava HDP system (2200, 1100, 555 and 277 trees ha^{-1}) concluded that medium density systems is best suited from view point of microbial activities. The root systems may act as precursors of nutrient release and spatio-temporal variations in soil properties in HDP system that determines the management modules to be adopted. Establishment of HDP system may not be suitable in all types of soil. A detailed analysis of clay, silt, sand contents are obvious as they impact the nutrient dynamics and storage. Adak *et al*. (2016a) confirmed that Zn, Cu and Fe storage had inverse relationship with clay + silt content and there was a tendency of decreasing levels of micronutrients in deeper soil depths (30–60 and 60–90 cm) as compared to the top layer (0–30 cm). Thus, the present study was laid out to assess the tree performances considering soil properties and foliar nutrients.

MATERIALS AND METHODS

Mango cv Dashehari planted at a spacing of 2.5 × 2.5, 2.5 × 5.0, 5.0 × 5.0, 5.0 × 7.5, 7.5 × 7.5 and 10.0 × 10.0 m accommodating 1600, 800, 400, 266, 178 and 100 trees ha^{-1} was selected for evaluating the performance of different density plantations (planted during August 1992) in research farm of Central Institute for Sub-tropical Horticulture, Rehmankhera, Lucknow, Uttar Pradesh, India (26.54º N Latitude, 80.45º E Longitude and 127 m above mean sea level) (Fig. 1). Uniform tree, soil, water management and plant protection measures were applied during study periods. NPK @1.0, 0.50 and 1.0 kg per tree was applied during the month of September-October each year in tree basin. Nutrient source in the form of Urea (2.17 kg), SSP (3.12 kg) and MOP (1.67 kg) was used. Tree growth, productivity and other related information were recorded. Undisturbed core soil samples were collected from tree basin in a randomized block design with four replications. Soil physical characteristics were determined in laboratory as per the standard methodology. Mechanical analysis was done using hydrometer method; sand, silt and clay of 26.2, 68.6, 5.2 percent in 2.5 × 2.5 m, 25.9, 68.7, 5.4 percent in 2.5 × 5.0 m, 33.6, 58.0, 8.5 percent in 5.0 × 5.0 m, 27.2, 62.9, 9.8 percent in 5.0 × 7.5 m, 27.2, 62.9, 9.8 percent in 32.5, 58.2, 9.3 percent in 7.5 × 7.5 m and 38.4, 53.7, 7.9 percent in 10.0 × 10.0 m planting systems was determined. Soil pH, soil organic carbon, available N (auto-N analyzer), available P (spectrophotometer) and available K (atomic absorption spectrophotometer) were estimated. The DTPA extractable Zn, Cu, Mn and Fe contents in the soil were also estimated (AAS). Recently mature leaf samples were collected and processed for analysis. Nitrogen was estimated by micro-Kjeldahl method whereas P by vanado-molybdate colorimetric method. Potassium and micronutrients Fe, Mn, Cu and Zn was analyzed in ICPE. Statistical analysis was performed using SPSS. All data were subjected to a one-way analysis of variance (ANOVA). Relationships between the parameters studied were quantified using Pearson's correlation coefficients. Histograms and correlation matrix were developed using SPSS software package. Required graphs were generated using MS Excel software.

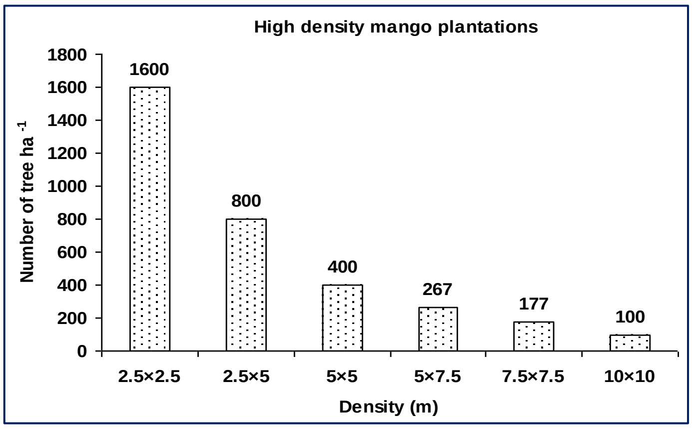

Figure 1. High density system in Mango cv Dashehari at Lucknow.

RESULTS AND DISCUSSION

Appraisal of vegetative growth and productivity level

A detailed study of vegetative growth pattern and productivity level was analyzed in different planting systems. The maximum tree height was recorded as 5.20, 5.40 and 5.55 m in 16^{th}, 18^{th} and 19^{th} yrs old Dashehari mango tree in higher density planting system (1600 trees ha^{-1}). In case of 800 trees ha^{-1}, the tree height was 5.15, 5.30 and 5.45 m respectively while minimum tree height of 4.50, 4.80 and 4.90 m in conventional planting system (100 trees ha^{-1}) respectively. The canopy spread was also studied and it was recorded that maximum canopy spread in north-south and east-west directions (5.47 m and 5.43 m) was recorded in 178 trees ha^{-1} and least in 1600 trees ha^{-1} (3.29 m and 3.22 m). Highest fruit yield was recorded in medium density planting (400 trees ha^{-1}) and the lowest being in traditional plantings (100 trees ha^{-1}). The observed highest yield was 15.12, 15.55 and 16.0 t ha^{-1} and minimum of 4.15, 4.60 and 5.50 t ha^{-1} in 16th, 18th and 19th yrs of old tree. Meland (1998) recorded one-third more yields in highest density as compared to the lowest density plantations over 7 yrs of plantations. Tardaguila *et al.* (2011) inferred for considering variations of soil properties in order to relate vegetative growth and yield components. Yadav *et al.* (2011) obtained fruit yield of 25.00 and 26.72 q ha^{-1} in Amrapali under high density system. Sharma *et al.* (2016) recorded higher productivity and profitability under HDP system in Amrapali through different nutrition sources. Similarly, Kumar *et al*. (2017) recommended for precision farming strategies for achieving greater sustainable yield in 20 yrs Dashehari Mango based on soil physico-chemical, foliar nutrient analysis, yield and yield components. Changes in soil physical properties as a function of orchard ground floor management system over a short or long-term basis was recorded (Adak *et al.* 2017). A range of 19.2–24.6 % WHC, 39.3–54.3 % porosity, BD of 1.27–1.48 and PD of 2.39–2.78 was estimated across 0–30 cm soil depth with 10 cm interval. Even, different micronutrient contents in Amprapali were observed among different planting systems (Raj *et al.* 2017). To improve the orchard sustainability, the role of soil micronutrients is obvious (Adak *et al*. 2012).

Soil properties and foliar nutrients in HDP systems

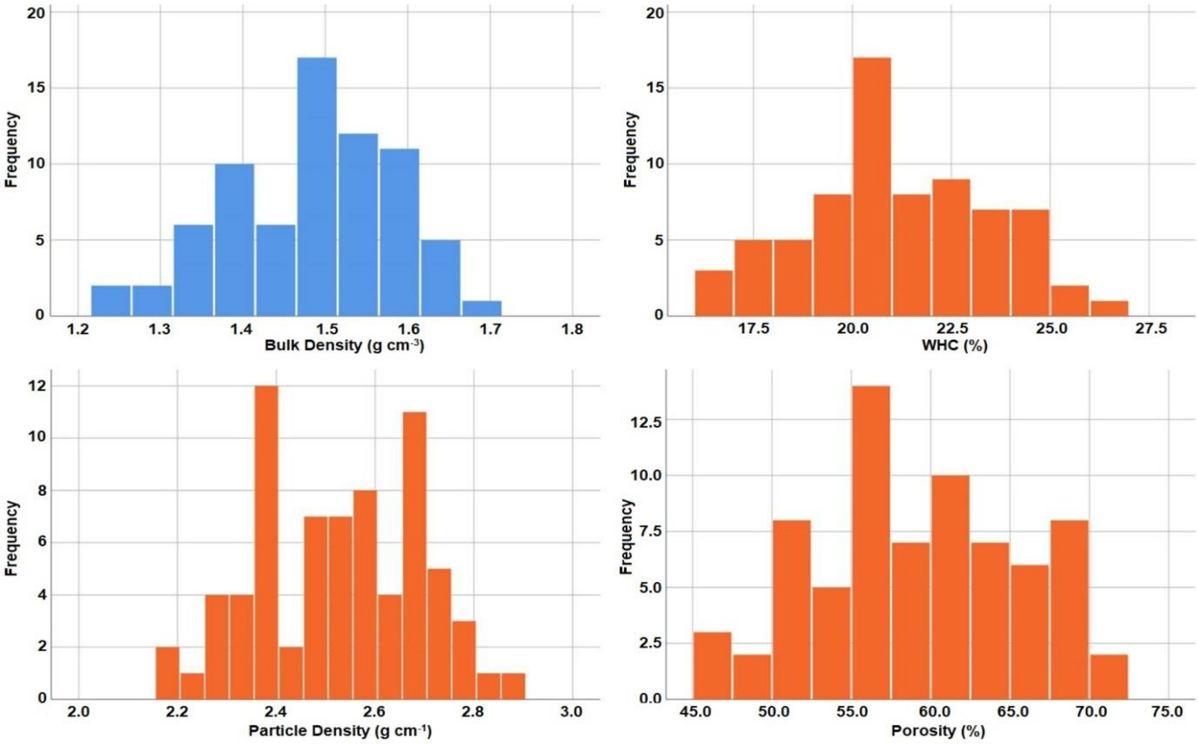

Figure 2. Histographic distribution of soil physical properties.

The univariate statistics analysis of soil parameters and foliar nutrients was tabulated in table 1 and 2. The estimated soil properties indicated that the soils of planting density systems had an average pH of 7.2 with 6.9 to 7.6 ranging values across six different spacing. Soil organic carbon is low and below critical level; with mean value of 0.38%. Soil available N, P and K was also at lower side of 66.92, 13.91 and 77.85 mg kg^{-1} respectively. Available Zn was deficient varying from 0.10–0.52 and average of 0.25 mg kg^{-1}. Average value of available Cu, Mn and Fe was 2.41, 6.48 and 5.71 mg kg^{-1} across HDP systems. Wide variations in terms of soil physical properties were recorded. A range of 16.6 to 26.1% water holding capacity was noted across systems with mean value of 21.2% while porosity ranged from 46.2 to 71.5% (mean 59.1%). Similarly, bulk density varied from 1.2–1.7 g cm^{-3} and particle density had values of 2.2–2.9 g cm^{-3}, respectively. Higher density plantations showed compaction in deeper depths; hence increased bulk density and lowers porosity. Histographic distribution depicted widespread distribution among the soil properties (Fig. 2–4). The distribution chart indicated maximum number of BD (10%), WHC (>5%), PD and SOC (>4%) and Porosity (>5%) frequency level. In case of micronutrients, highest Zn, Mn and Fe had frequency level >15% while Cu up to 20%. Foliar nutrient analysis showed need for proper nutrient management for achieving potential yield. The mean N, P and K content of 1.7, 0.14 and 1.30% was recorded. The micronutrients were found to be varied widely; average values around 10.33, 29.24, 96.17 and 190.24 mg kg^{-1} of Zn, Cu, Mn and Fe content was noted respectively.

Table 1. Univariate statistics of soil parameters under high density mango plantations of subtropical region of Lucknow, India.

Soil parameters	Range	Mean	Standard deviations	Standard error of mean	CV %	Skewness	Kurtosis
pH	6.9–7.6	7.20	0.19	0.002	9.6	0.51	-0.13
Available N (mg kg^{-1})	29.0–98.0	66.92	14.04	1.30	21.0	-0.17	0.56
Available P (mg kg^{-1})	5.7–30.7	13.91	5.19	0.18	37.3	0.89	0.40
Available K (mg kg^{-1})	32.9–115.5	77.85	18.07	2.20	23.2	-0.28	-0.01
Soil organic carbon (%)	0.12–0.66	0.38	0.13	0.001	34.6	0.22	-1.01
Available Zn (mg kg^{-1})	0.10–0.52	0.25	0.09	0.001	36.6	0.63	-0.03
Available Cu (mg kg^{-1})	0.58–10.16	2.41	1.87	0.024	77.7	2.33	6.32
Available Mn (mg kg^{-1})	2.92–15.38	6.48	2.15	0.032	33.2	1.29	2.81
Available Fe (mg kg^{-1})	2.76–12.08	5.71	1.65	0.019	28.8	0.85	1.04

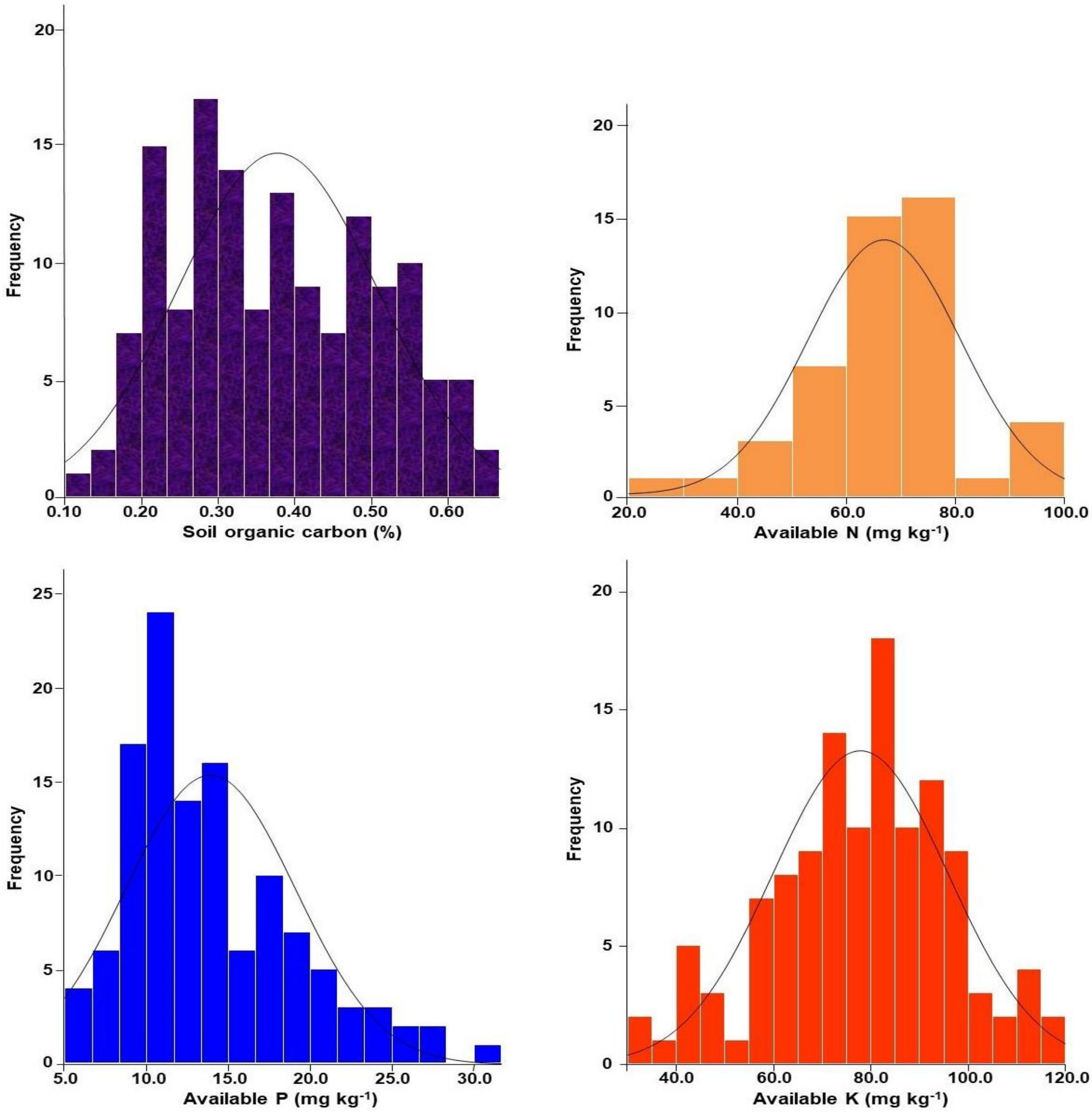

Figure 3. Frequency distribution of SOC, available N, P and K across high density mango orchard soils.

Sustainability of high-density plantations depends on a number of factors associated with production levels; some are directly while others are indirectly impacting the gap between observed vs. potential productivity. Maintenance of optimum canopy architecture, tree brunch angle, pest protection and moreover declines in soil organic matter levels, surface water quality degradation, reduced water infiltration rates and other soil physical parameters may impact on its below satisfactory level of production (Mishra & Adak 2009, Kumar &

Ravishankar 2011). Management options play crucial role as the gap between supply and demand leads to the nutrient deficiency and thereby yield sustainability and orchard health (Perry *et al.* 2010, Srikasetsarakul *et al.* 2011, Prakash *et al.* 2011). Ahmad *et al.* (2003) evaluated the performance of different nutrition sources under high-density planting in Amrapali mango. Gucci *et al.* (2012) recorded variable yield performances and changes in soil properties as a function of soil management system in high-density olive orchard. Adak *et al.* (2014) recorded yield improvement in Dashehari mango under quality fertigation programme wherein soil organic carbon, available P and K improvement in topsoil layer (0–30 cm) was noted. The role of soil compaction in higher density plantation system (>400 trees ha^{-1}) might have decreased the yield. Even the soil organic carbon and micronutrient stocks played a significant role on nutrient transformations. It was estimated that these systems could store <9.0 mg ha^{-1} soil organic carbon. Further, >50% Zn stock lies in the 1.1 to 1.5 kg ha^{-1}, >60% Cu stock in 11 to 20 ha^{-1} category, near to 70% Mn in 31 to 40 ha^{-1} and upto 50% Fe stock of 21-30 ha^{-1} category, which may utilize the reserve source for nutrient release (Adak *et al.* 2016b). A clear understanding of the soil organic carbon dynamics indicates the potential benefits of quality fruit production. The storage of soil organic carbon was observed higher in HDP system as compared to a conventional system, thus the role of organic management becomes crucial in HDP system in terms of organic carbon mediated nutrient availability and its dynamics (Adak *et al.* 2015). Based on a study in high-density guava plantation system having 555, 277 and 5000 trees ha^{-1}, it was found that availability of P, K and organic carbon content was higher in 555 and 5000 trees ha^{-1} than conventional system (277 trees ha^{-1}). Stocks of micronutrients were calculated and data showed that HDP system could store more nutrients in root zone depth of 0–30 cm soil but proper precision farming is needed for better productivity (Adak *et al.* 2016c).

Table 2. Univariate statistics of foliar nutrients in high density mango plantations of subtropical region of Lucknow, India.

Soil parameters	Range	Mean	Standard deviations	Standard error of mean	CV %	Skewness	Kurtosis
N (%)	1.2–2.2	1.70	0.20	0.001	13.8	0.03	-0.09
P (%)	0.09–0.19	0.14	0.02	0.001	15.9	-0.10	-0.28
K (%)	0.66–1.96	1.30	0.36	0.003	27.5	-0.16	-1.06
Zn (mg kg^{-1})	3.0–20.0	10.33	4.2	0.42	41.0	0.56	-0.33
Cu (mg kg^{-1})	0.1–70.0	29.24	2.5	1.98	73.5	0.43	-0.89
Mn (mg kg^{-1})	25.0–208.0	96.17	5.3	7.57	55.4	0.38	-0.96
Fe (mg kg^{-1})	106.0–392.0	190.24	5.2	5.09	27.5	1.60	4.30

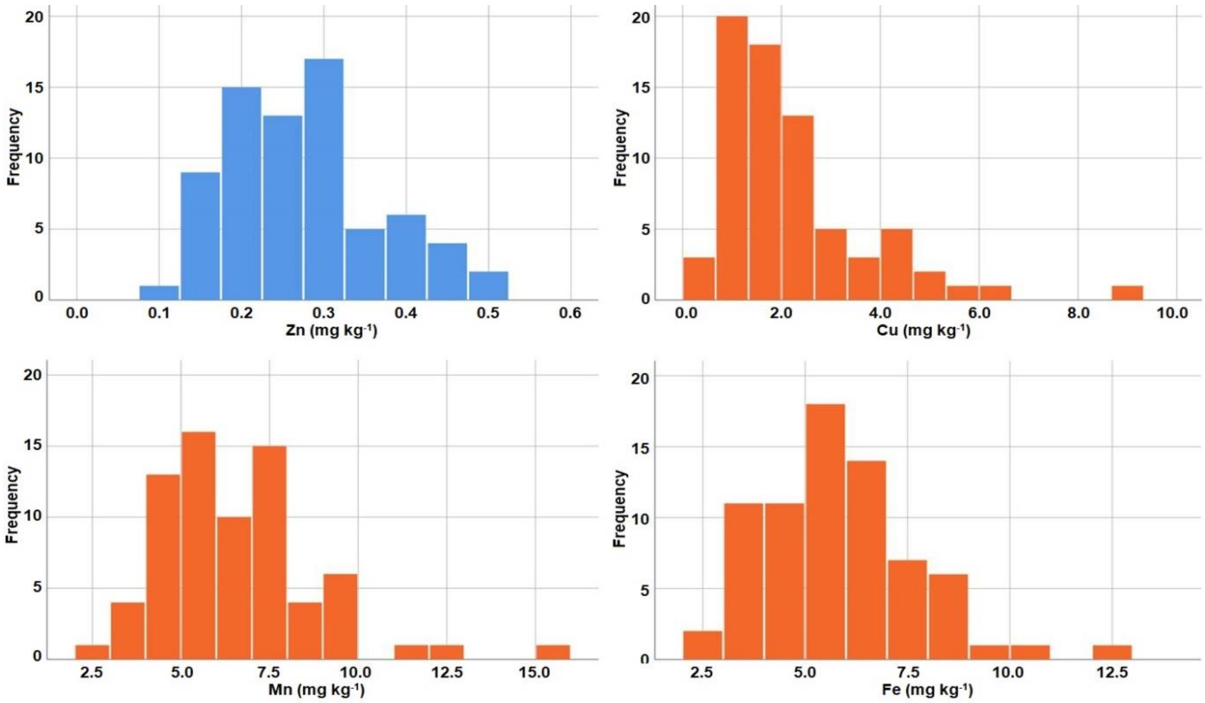

Figure 4. Histographic distribution of soil micronutrients.

Correlation among the soil properties

The correlation study indicated the positive and significant correlation of soil organic carbon with the other soil nutrients (Table 3). It emphasizes the fact that there is an urgent need for optimum nutritional management in the soils of the high density plantation system in order to sustain the productivity level as well as nutrient release to plants. Soil organic C significantly correlated with N (0.328*), P (0.363**), K 90.287**), Zn (0.453**), Cu (0.389**), Mn (0.339***) and Fe (0.438**). Likewise available P, K had a positive correlation with the micronutrients. The positive correlation among these soil properties indicated the positive effect of each nutrient on quality fruit production. Adak *et al.* (2014) observed positive correlation of yield with SOC (r=0.994**) and soil nutrients (r=0.898* to 0.994**). Even available K and P was significantly correlated with acidity, ascorbic acid (r=0.865* to 0.921**).

Table 3. Correlation matrix of soil nutrient parameters under high density mango plantations of subtropical region of Lucknow, India.

Soil parameters (mg kg^{-1})	SOC (%)	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})
SOC (%)	1	.328(*)	.363(**)	.287(**)	.453(**)	.389(**)	.339(**)	.438(**)
Available N		1	.354(*)	NS	NS	.330(*)	NS	NS
Available P			1	.477(**)	.516(**)	.597(**)	.320(**)	.425(**)
Available K				1	.670(**)	.468(**)	NS	.486(**)
Available Zn					1	.587(**)	.397(**)	.557(**)
Available Cu						1	.218(*)	.495(**)
Available Mn							1	.358(**)
Available Fe								1

Note: * = Correlation is significant at the 0.05 level, ** = Correlation is significant at the 0.01 level.

CONCLUSION

It was inferred from the present study that high density system of plantations are fruitful for getting higher yields as compared to traditional cultivation. Among the HDP system, medium density is the best and may be recommended at farmers' field in order to maintain satisfactory yield level. Farmers could get Dashehari mango yield of 15–16 t ha^{-1} or even higher based on canopy and nutrient management. Nutrient data indicated wide variations across these density plantation systems. Impacts of density on soil physical properties were also observed. Need for proper management system is still required for getting more yields.

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