INTERACTION OF FARMYARD MANURE AND PLANT POPULATION DENSITY EFFECTS ON SOIL CHARACTERISTICS AND PRODUCTIVITY OF MULCHED STRAWBERRY IN A TROPICAL CLIMATE

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ABSTRACT

The cultivated strawberry (*Fragaria ananassa*) is a perennial herbaceous plant, whose berries are principally consumed fresh or after processing into preserves, jam, jelly, juice, or flavours. Information on the influence of farmyard manure (FYM) and plant population density (PPD) on strawberry performance in the tropics is meager. The present study determined the effects of FYM and PPD on soil characteristics, growth, fruit yield and quality of mulched strawberry under tropical conditions. The experiment was laid in a split block design, replicated three times and conducted in two crop years. Farmyard manure (0, 10, 30 and 60 t/ha) formed main plots, while PPD (71,111, 53,333 and 40,000 plants/ha) formed strip plots. Parameters measured were: soil pH, cation exchange capacity (CEC), nutrient content and temperature. Plant parameters were: leaf tissue nutrient content, chlorophyll content, number of leaves, number of runners, canopy diameter, root and shoot biomass, number of berries, weight of berries per plant and total soluble solids (TSS) per plot. The data were subjected to analysis of variance. Manure significantly ($P<0.05$) increased soil CEC. The 40,000 plants/ha PPD significantly raised soil temperature at 10 cm depth. The effect of interaction between FYM and PPD was significant on leaf tissue Mn content. The 60 t/ha FYM significantly ($P<0.05$) increased number of leaves. Plant population density significantly ($P<0.05$) decreased number of runners, but increased number and weight of berries. The interaction between FYM and PPD significantly ($P<0.05$) affected TSS. It is recommended that 53,333 to 71,111 plants/ha be adopted to realise 47% to 92% higher strawberry fruit weight. Further research is recommended to determine the FYM rate that significantly increases fruit yield.

Key words: CEC, *Fragaria ananassa*, Fruit yield, Growth, Mineral nutrients, Spacing, Soil temperature, Total soluble solids

INTRODUCTION

Strawberry (*Fragaria ananassa* Duch.) is a perennial herbaceous plant with short and thick stems called crowns that bear buds, which develop into either long slender stems called runners or into flowers (Edmond et al., 1994). Strawberry root system is shallow, moderately extensive and hence a surface-feeder. Consequently good production is promoted by soil that is free of clods and pests, well aerated to promote healthy root growth, plant vigour and satisfactory berry yields (Welch, 1989). Strawberry yields are more frequently reduced by lack of water, poor soil drainage and poor soil physical properties than by lack of synthetic fertiliser (Hoover et al., 2003). In Kenya, 200 kg/ha double super phosphate, 30 t/ha FYM, and 45 cm x 60 cm spacing are recommended for growing strawberries.

Farmyard manure (FYM) is an important source of essential plant nutrients and organic matter for crop production in the small-holder sector and can help farmers reduce inputs of commercial fertilisers and increase enterprise profitability (Mubonderi et al., 1999). It contains a broad range of plant nutrients although at a lower concentration than inorganic fertilisers. A large portion of feeds initially ingested by animals contains generally 75% nitrogen, 80% phosphorous and 90% potassium upon excretion (Miles et al., 2002). Recent improvements in organic strawberry production have resulted in yields as high as 89% of that obtained from conventional production. Organically grown strawberries can be sold at a premium price, thus offsetting yield reduction (Anonymous, 1996).

Strawberry planting and training systems vary greatly. In the hill system, mother plants are set close together and runners are pruned off or prevented from rooting to form new plants. On the other hand, a matted row system is where most of the runner plants from each mother plant are permitted to root in the row at random to a predetermined width. In the spaced matted row system, a predetermined small number of early daughter plants from each mother plant are anchored at a suitable distance (equidistant) around the mother plant. However, a solid set/bed system is where all runners are permitted to expand and root and no attempt is made to maintain discrete rows (Logsdon, 1974; Galletta and Himelrick, 1990).

It follows that in strawberry production PPD and spacing vary, resulting in variation in yields and fruit quality. Plant spacing varies depending on the vigour of the cultivar planted, planting system, soil type, growers' preferences, runner production and irrigation system (Denisen, 1979; Welch, 1989). Furthermore, size of farm equipment and tyre spacing must be taken into account when planning the spacing of strawberry row centres (Himelrick et al., 1996). Increasing planting density from 57,700 to 87,000 plants/ha increased marketable yields from 23.4 to 27.4 t/ha (Freeman, 1981). Sarooshi and Cresswell (1994) made a similar observation, whereby marketable yields increased from 16.4 to 23.4 t/ha when density was increased from 53,500 to 93,500 plants/ha in hydroponically grown strawberries. The higher yields were attributed to greater number of plants per unit area, although at the expense of fruit acidity and yield per plant.

Strawberry plant vigour and performance may be influenced by ecological conditions as well. Choice of cultivar is more crucial in strawberry than in most other crops, because each clone has a very definite area or climatic zone to which it is adapted (Galletta and Himelrick, 1990). The main cultivar grown in Kenya is Cambridge Favourite (Epenhuijsen, 1976). It is an English variety that is highly resistant to leaf spot, fairly vigorous, mid-season heavy cropper of very large, well-shaped, fair flavoured and brilliantly coloured fruits (Barbara, 1956; Wright, 1973; Anonymous, 1997).

Although FYM and PPD are known to influence good strawberry growth and high quality fruit yield, there is conflicting information on FYM rates and PPD to use for optimal yield and fruit quality, particularly in the tropics. Presently, most of the fertilizer and spacing recommendations used have been adopted from western countries, where they suit ecological conditions and farm equipment. The present research studied the effects of FYM and PPD on soil characteristics, growth, fruit yield and quality of mulched strawberry under tropical conditions. The hypotheses tested were that FYM and PPD maximise the quantity and quality of strawberry yields through modification of soil characteristics and complementation of their individual effects.

MATERIALS AND METHODS

The research was conducted on horticultural experimentation plots on Tatton farm of Egerton University, located at latitude 0^{o}23' south, longitude 35^{o}35’ east, and 2200 m above sea level. The soils on the farm are well-drained, deep, friable, silty clay loams classified as haplic Phaeozem (Jaetzold and Schmidt, 1983). The farm receives bimodal rainfall, with long rains from March to August and short rains from October to December. The average annual rainfall received is 1019 mm. Maximum and minimum temperatures range from 19^{o}C to 22^{o}C and 5^{o}C to 8^{o}C, respectively. On a seasonal basis, the period from June to August experiences lower temperatures than the rest of the year.

The experiment was laid out in a split-block design with three replications. Farmyard manure (0, 10, 30 and 60 t/ha) formed main plots. Plant population density (71,111, 53,333 and 40,000 plants/ha, corresponding to spacing of 30cmx30cm, 30cmx45cm and 45cmx45cm, or 16, 12 and 9 plants/2.25 m^2 plot, respectively) formed strip plots. The experiment was conducted in two years, from August 2003-May 2004, and from February-November 2004, in different plots to avoid residual effects of treatments on subsequent plants.

Land was ploughed to a fine tilth, followed by construction of 10-cm high beds. Well decomposed cattle FYM was broadcasted on the beds and incorporated into the soil to a depth of 15 cm. The beds were levelled and mulched with black polyfilm of gauge 500. Drip tubes (2.5 cm diameter) were placed on the beds beneath the polyfilm and used to irrigate the plants for 9 hours per day and three days in a week.

Runners of cultivar Cambridge Favourite were obtained from the National Horticultural Research Centre in Thika and propagated on Tatton farm. Runner plants of similar growth stage were uprooted from the propagation plots and prepared for planting the experiment. Dead and senescent roots, runners and leaves were removed from them. Holes were made through the polyfilm mulch where runners were inserted into the soil. Runners and flower stalks were removed bi-weekly during the first three months after planting to promote growth of crowns for maximum productivity. Plant diseases and insect pests were monitored and controlled using ridomil at factory recommended rate for powdery mildew and Kelthane at a rate of 60 ml/20 litres of water for mites, thrips and whiteflies.

Soil and FYM were analysed for pH, CEC and mineral nutrient content, while strawberry leaf tissues were analysed for mineral nutrient content following standard procedures (Hinga et al*.,* 1980; Okalebo et al., 2002). Soil and leaf tissue samples were taken from each strip plot at 24 weeks after planting (WAP). Chlorophyll content was determined by taking the youngest representative, fully expanded leaf from each plant in a strip plot at 44 and 28 WAP for seasons 1 and 2, respectively. Chlorophyll was extracted using methods described by Harbone (1984). Absorbence of extracted chlorophyll was read in a spectrophotometer (Model 632, China) at wavelengths 646 nm and 663 nm. Total chlorophyll content (mg/L) = 17.30A646 + 7.18A663.

Soil temperature was measured using soil thermometers inserted at 10 cm and 15 cm depths on each strip plot. Readings were taken daily at 8:00 am and 2:30 pm (when soil temperatures were minimum and maximum, respectively) from 5 WAP to 9 WAP. The minimum and maximum temperatures were averaged to get average daily temperature, which were in turn averaged over each growing season.

Plant growth measurements were taken from 15 WAP to 23 WAP at bi-weekly intervals. Canopy diameter was measured by stretching a tape measure along the widest region of each plant to the canopy drip line. Leaves on all plants in each strip plot were counted and divided by the number of plants in the plot to get the average leaf count per plant. Runners on all plants in each strip plot were pruned off, counted and divided by the number of plants generating them to obtain average number of runners per plant. New runners continued to develop on the plants over time. One plant per plot was uprooted at 24 WAP. The roots were cut off and cleaned with water followed by oven-drying at 65°C for 72 hours and weighing on a balance. Red-ripe berry harvesting began at 25 WAP and was done at fortnightly intervals. The total number of berries was divided by the number of plants generating them to obtain berries per plant. The berries for each strip plot were weighed to obtain total weight, which was divided by the number of plants in the respective strip plot to get berry weight per plant. The number and weight of berries per plant were multiplied by respective plants per hectare to get yield per hectare. Three berries were randomly selected from each plot and analyzed for total soluble solids (TSS) using a hand-held refractometer.

The data for all measured parameters were subjected to analysis of variance using MSTAT-C computer programme to determine the effect of FYM and PPD on strawberry soil characteristics, growth, fruit yield and quality. All counts data were transformed using logarithm to base 10 for number of leaves and berries, and square rooting for number of runners before being subjected to analysis of variance. The transformed counts were back-transformed to actual counts for reporting. Mean separation was done using the Least Significant Difference test at P=0.05.

RESULTS AND DISCUSSION

Effect of FYM and PPD on Soil pH, CEC and Mineral Nutrients

The initial soil characteristics were: 6.1 pH, 0.56% total N, 67 ppm available P, 714 ppm available K, 94 ppm available Ca, 267 ppm available Mg, 75 ppm available Fe, 3.3 ppm available Zn, 0.4 ppm available Cu, 559 ppm available Mn. The initial FYM characteristics were: 7.4 pH, 1.69% total N, 319 ppm available P, 619 ppm available K, 1177 ppm available Ca, 627 ppm available Mg, 3.7 ppm available Fe, 3.8 ppm available Zn, 0.8 ppm available Cu, 397 ppm available Mn. Soil pH, total N and available macronutrients were higher in FYM than in soil. In contrast, soil available micronutrients were less in FYM than in soil, probably due to the heterogeneity of soil (Brady and Weil, 1999). Alternatively, the micronutrients may have been lost through leaching during decomposition of FYM (Marschner, 1986).

Farmyard manure, PPD, and their interaction had no significant (P>0.05) effect on final soil pH, which ranged from 5.9 to 6.5. Nevertheless, increasing rates of FYM tended to elevate the soil pH, as evidenced by 60 t/ha FYM that raised soil pH from 6.0 to 6.3. Therefore, repeated application of FYM is likely to raise soil pH as observed previously (Patiram and Singh, 1993; Whalen et al. 2000; Shen and Shen, 2001). The increase in soil pH due to manure has been attributed to buffering from bicarbonates, organic acids (Whalen et al., 2000), decrease in Al^{3+} and release of basic cations of Ca^{2+}, Mg^{2+} and K^{+} (Patiram and Singh, 1993; Shen and Shen, 2001). These reports also agree with results of the present study in which FYM raised the available Ca, Mg and K. Soil pH, however, has been shown to decline in some manure-amended soils. Thus, the effect of FYM on soil pH depends on the FYM source and soil characteristics (Whalen et al., 2000).

Farmyard manure significantly ($P<0.05$) increased CEC (Table 1). The higher rates of FYM (30 t/ha and 60 t/ha) resulted in significantly higher CEC than the lower rates of FYM (0 t/ha and 10 t/ha).

Table 1. Effect of FYM and PPD on soil and leaf tissue characteristics [z]

Variable & PPD (plants/ha)	FYM (t/ha)				
CEC (meq/100 g soil)	0	10	30	60	Mean
71,111	28.0	27.4	29.5	30.5	28.9
53,333	28.2	29.2	30.0	30.6	29.5
40,000	28.9	28.2	30.5	30.0	29.4
Mean	28.4[b]	28.3[b]	30.0[a]	30.4[a]	
$LSD_{0.05}$ FYM = 1.094					
Initial soil CEC = 26.4					
Leaf tissue calcium (ppm)					
71,111	12,354	11,267	10,567	10,334	11,131[b]
53,333	10,567	9,557	11,500	12,044	10,917[b]
40,000	12,976	13,598	12,044	11,678	12,574[a]
Mean	11,966	11,474	11,370	11,352	
$LSD_{0.05}$ PPD = 739					
Leaf tissue manganese (ppm)					
71,111	76[abc]	66[c]	93[ab]	67[c]	75
53,333	95[a]	84[abc]	74[bc]	89[ab]	85
40,000	74[bc]	81[abc]	90[ab]	83[abc]	82
Mean	82	77	86	80	
$LSD_{0.05}$ Interaction = 18					
Soil temp. at 10 cm depth					
71,111	20.6	20.6	20.3	20.5	20.5[b]
53,333	21.1	20.9	20.3	20.9	20.8[b]
40,000	21.7	21.5	21.7	21.7	21.7[a]
Mean	21.1	21.0	20.8	21.0	
$LSD_{0.05}$ PPD = 0.78					

[z] Values followed by the same letter or no letter within each factor of each variable are not significantly different at $P=0.05$, according to LSD test.

This means that soils receiving FYM are likely to be more fertile and rich in exchangeable cations (Mg and Ca). The increase in CEC due to application of FYM is attributed to the colloidal nature of FYM (Marschner, 1986; Patiram and Singh, 1993).

Farmyard manure, PPD and the interaction between FYM and PPD had no significant (P>0.05) effect on soil available nutrients. Nevertheless, increasing rates of FYM increased soil available macronutrient content, especially phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg), and Manganese (Mn). The ranges of final soil available nutrients were: 69 to 81 ppm P, 611 to 665 ppm K, 70 to 84 ppm Ca, and 225 to 292 ppm Mg, depending on treatment. The increases are in agreement with previous findings (Albregts and Howard, 1981; Patiram and Singh, 1993; Whalen et al., 2000; Shen and Shen, 2001). Increasing rates of FYM slightly reduced soil available iron (Fe), which ranged from 61 to 64 ppm. As FYM increased there was little variation in soil available zinc (Zn) and copper (Cu), which ranged from 3.4 to 3.5 ppm and 1.5 to 1.7 ppm, respectively. These results were attributed to their low levels in FYM, possible immobilization in the soil (Whalen et al., 2000), and antagonism by other nutrients (Tisdale et al., 1993; Katyal and Randhawa, 1983).

Effect of FYM and PPD on Leaf Tissue Nutrient Content

Farmyard manure did not significantly (P>0.05) affect all leaf tissue mineral nutrient contents, whose ranges were: 0.78% to 0.86% N, 3481 to 3655 ppm P, 13521 to 15343 ppm K, 11352 to 11966 ppm Ca, 1585 to 1979 ppm Mg, 206 to 300 ppm Fe, 19 to 26 ppm Cu, 6.0 to 6.4 ppm Zn, and 77 to 86 ppm Mn, depending on treatment. The reason for decreasing leaf tissue N content was probably slow release and/or denitrification of N making it unavailable for plant uptake (Whalen et al., 2000). Since soil available nutrients were not significantly affected by FYM, the non-significant effect of FYM on leaf tissue mineral nutrient content is not unexpected. Locascio et al. (1977) reported that 1.5% leaf tissue K is the critical range for strawberry, while 3.1% to 3.5% leaf tissue N is above the critical range. Zinc leaf tissue content was in the deficiency range, the sufficiency one being 25 to 150 ppm (Tisdale et al., 1993; Katyal and Randhawa, 1983). Leaf tissue Mn content was within the normal range of 20 to 500 ppm for most plants. For optimum plant growth, the ratio of Fe to Mn should be between 1.5 and 2.5 (Katyal and Randhawa, 1983). In the present study, the ratio of Fe to Mn ranged from 2.6 to 3.5, which was excess. Thus, the strawberry plants under the present study suffered some nutrient imbalances.

On the other hand, PPD significantly ($P<0.05$) reduced leaf tissue Ca content only (Table 1). The 71,111 plants/ha and 53,333 plants/ha resulted in lower leaf tissue Ca content than the 40,000 plants/ha (Table 1). There was a significant ($P<0.05$) interaction effect of FYM and PPD on leaf tissue Mn content only (Table 1). The highest Mn content was recorded for 0 t/ha FYM and 53,333 plants/ha. Generally, low FYM rate and low PPD regime resulted in higher leaf tissue Mn content than high FYM rate and low PPD regime. These results for PPD and interaction were attributed to reduced slow release and competition among nutrients under high FYM and low PPD. In all cases, leaf mineral nutrient content was higher than the corresponding soil mineral nutrient content, except Mn. These results indicated that strawberry plants were absorbing the nutrients from the soil.

Effect of FYM and PPD on Leaf Chlorophyll Content

Farmyard manure, PPD and their interaction did not significantly ($P>0.05$) affect leaf chlorophyll content in both years. However in year 1, increasing FYM rates tended to reduce leaf chlorophyll content. In year 2, there was little variation in leaf chlorophyll content among the different FYM rates. Regardless of year, leaf chlorophyll content under the influence of FYM ranged from 21 mg/L to 24 mg/L, while under the influence of PPD ranged from 23 mg/L to 24 mg/L. Leaf chlorophyll content obtained in year 1 was close to that obtained in year 2. Thus, there was no major effect of year, or timing of measurement on leaf chlorophyll content. Decrease in chlorophyll content was attributed to several factors such as low soil fertility and salinity. The insignificant effect of FYM on chlorophyll content was attributed to low leaf tissue N, otherwise necessary in synthesis of both chlorophylls A and B (Brady and Weil, 1999; Tisdale et al., 1993)

Effect of FYM and PPD on Soil Temperature

There was no significant ($P>0.05$) effect of FYM on soil temperature at 10 cm and 15 cm depths (Table 1). However, increasing rates of FYM slightly reduced soil temperature. The slight reduction in soil temperature concurred with the fact that FYM increases soil organic matter with good water holding capacity that in turn lowers temperature (Brady and Weil, 1999; Anonymous, 1995). Plant population density significantly ($P<0.05$) reduced soil temperature at 10 cm depth (Table 1). The lower PPD of 40,000 plants/ha resulted in a higher soil temperature than the higher PPD of 53,333 plants/ha and 71,111 plants/ha. This result was attributed to low shading by leaves under the low PPD. There was no significant ($P>0.05$) interaction effect of FYM and PPD on soil temperature at both depths (Table 1).

Effect of FYM and PPD on Number of Leaves

Farmyard manure significantly (*P*<0.05) increased the number of leaves at 17, 19 and 23 WAP (Table 2). The 60 t/ha FYM produced significantly (*P*<0.05) more leaves than the control. However, the 10 t/ha and 30 t/ha FYM were not significantly different in their effect on number of leaves. There was a gradual increase in the number of leaves from 22 to 72 from 15 to 23 WAP. The significant effect was attributed to the slight increase in available soil nutrients and improvement of soil physical characteristics with increasing FYM rates (Breen and Martin, 1981; Marschner, 1986).

The effect of PPD and the interaction between FYM and PPD did not significantly (*P*>0.05) affect the number of leaves throughout the experimental period (Table 2). This result implied that strawberry plants do not take advantage of reduced PPD to initiate more leaves, because low PPD should have increased the number of leaves through reduced interplant competition for plant nutrients (Galletta and Himelrick, 1990). They are, however, in agreement with those of Ferree (1988), who observed high light interception under low PPD inhibit leaf growth.

Table 2. Effect of FYM and PPD on number of leaves per plant at various times [z]

Time (WAP)		FYM (t/ha)				
17	PPD (plants/ha)	0	10	30	60	Mean
LSD $_{0.05}$ FYM = 1.1	71,111	29	32	29	32	30
	53,333	29	32	32	37	32
	40,000	27	29	29	34	29
	Mean	29[b]	31[b]	30[b]	34[a]	
19	71,111	40	40	37	40	39
LSD $_{0.05}$ FYM = 1.1	53,333	37	43	37	47	41
	40,000	34	70	37	47	39
	Mean	37[b]	41[a]	37[b]	44[a]	
23	71,111	59	59	59	68	61
LSD $_{0.05}$ FYM = 1.0	53,333	68	68	63	74	68
	40,000	59	59	59	74	62
	Mean	62[b]	62[b]	60[b]	72[a]	

[z] Values followed by the same letter or no letter for each variable within a time of assessment are not significantly different at *P*=0.05, according to LSD test.

Effect of FYM and PPD on Number of Runners

Farmyard manure did not significantly (*P*>0.05) affect the number of runners throughout the growing period (Table 3). Generally, the number of runners ranged from 2 to 6. This response was attributed to the low nitrogen in the FYM, low nutrient use efficiency in manure-treated plots and competition with leaf growth. Tworkorski et al. (2001) obtained increased number of runners with increase in nitrogen rates.

Table 3. Effect of FYM and PPD on number of runners per plant at various times [z]

Time (WAP)		FYM (t/ha)				
17	PPD (plants/ha)	0	10	30	60	Mean
LSD $_{0.05}$ PPD = 0.03	71,111	4	3	3	3	3^b
	53,333	4	3	3	4	3^b
	40,000	1	4	4	5	4^a
	Mean	4	3	3	4	
19						
LSD $_{0.05}$ PPD = 0.02	71,111	4	3	2	3	3^b
	53,333	4	4	3	3	3^b
	40,000	5	4	4	5	4^a
	Mean	5	4	3	4	
21						
LSD $_{0.05}$ PPD = 0.40	71,111	4	3	3	3	3^b
	53,333	4	4	3	3	3^b
	40,000	6	4	4	4	5^a
	Mean	4	4	3	3	

[z] Values followed by the same letter or no letter for each variable within a time of assessment are not significantly different at P=0.05, according to LSD test.

On the other hand, PPD significantly (P<0.05) decreased the number of runners at 17, 19 and 21 WAP (Table 2). The lowest PPD induced a higher number of runners than the intermediate and highest PPD, as expected. The interaction of FYM and PPD did not have a significant (P>0.05) effect on number of runners (Table 2). The low PPD resulted in higher number of runners perhaps due to reduced interplant competition for soil resources. In addition, high light intensity which reportedly favours runner production could have been received under the low PPD (Ferree, 1988; Galletta and Himelrick, 1990).

Effect of FYM and PPD on Canopy Diameter

Farmyard manure, PPD, and their interaction had no significant (P>0.05) effect on canopy diameter throughout the experimental period, although diameter increased with increasing FYM and age of strawberry plants. Canopy diameter increased from 27 cm to 40 cm per plant over time and tended to be narrower for 0 t/ha FYM than for 60 t/ha FYM, and for the higher PPD than for the lower PPD. The promotion of canopy spread by FYM was attributed to the fact that FYM significantly increased number of leaves (Breen and Martin, 1981). Reduced interplant competition for resources by the lower PPD accounted for the slightly higher canopy diameter (Galletta and Himelrick, 1990).

Effect of FYM and PPD on Root Biomass

The effects of FYM, PPD, and their interaction was not significant (P>0.05) on root biomass, which ranged from 13.3 to 15.8 g/plant. This lack of a significant effect by FYM and PPD on root biomass showed that the P provided by FYM enhanced root growth to the same extent and the roots under the different PPD grew similarly because they were subjected to similar environments of the root-growth-promoting P. The total P content detected (65 to 84 ppm) was higher than what has been found to be sufficient for strawberry productivity (60 ppm) (George and Albergts, 1994). Nevertheless, the lowest root biomass resulted for 10 t/ha FYM plus the highest PPD, and the highest root biomass resulted for 60 t/ha FYM plus the lowest PPD, corresponding to high and low competition, respectively.

Effect of FYM and PPD on Number, Weight and Quality of Berries

Farmyard manure did not significantly (P>0.05) affect the number of berries, although increasing FYM rates either produced the same or slightly lower number of berries (Table 4). Farmyard manure did not significantly (P>0.05) affect the weight of berries (Table 4). Nevertheless, increasing FYM rates resulted in berries that weighed slightly less than the berries for the 0 t/ha FYM (Table 4).

Table 4. Effect of FYM and PPD on total fruits, fruit weight and total soluble solids

Variable and PPD (plants/ha)	FYM (t/ha)				
Total fruits/ha	0	10	30	60	Mean
71,111	1,468,926	1,468,926	1,358,313	1,468,926	1,438,799^{a}
53,333	1,258,925	1,078,947	1,258,925	1,258,925	1,210,598^{a}
40,000	857,038	794,328	736,207	857,038	809,096^{b}
Mean	1,166,810	1,078,947	1,078,947	1,166,810	
LSD $_{0.05}$ PPD = 1.5					
Fruit weight (t/ha)					
71,111	2.7	2.4	2.3	2.4	2.5^{a}
53,333	2.1	1.9	2.0	1.9	2.0^{a}
40,000	1.3	1.2	1.1	1.4	1.3^{b}
Mean	2.0	1.8	1.8	1.9	
LSD $_{0.05}$ PPD = 0.54					
TSS (% sugar)					
71,111	7.0^{bcd}	6.6^{d}	6.7^{cd}	7.1^{bc}	6.8
53,333	6.9^{cd}	6.5^{d}	6.6^{cd}	6.7^{cd}	6.7
40,000	7.6^{a}	6.5^{d}	6.5^{d}	7.4^{ab}	7.0
Mean	7.2^{a}	6.6^{c}	6.6^{bc}	7.1^{ab}	
LSD $_{0.05}$ FYM*PPD = 0.43. LSD $_{0.05}$ FYM = 0.46					

[z] Mean followed by the same letter or no letter within each factor of each parameter are not significantly different at P=0.05, according to the LSD test.

Kaya et al. (2001) reported 47% and 34% fruit yield reduction for 'Oso Grande' and 'Camarosa' strawberry varieties, respectively, due to the salinity in soil. Locascio et al. (1977) reported that soluble salts that exceed 2.3 to 2.5 mmhos/cm of conductivity in saturated extracts (about 2650 to 2900 ppm at 10% soil moisture) reduce strawberry yields by 50%. Soluble salts in the present study were most likely contributed through FYM, whose initial pH was 7.4 (Brady and Weil, 1999; Whalen, et al. 2000; Hao, 2003). Yield limitation by FYM in the present study was also attributed to low available N and K in FYM, probably caused by slow release (Marschner, 1986). Albregts et al. (1991) attributed the low strawberry fruit weight to N and K deficiency. It is also possible that nutrient imbalance limited strawberry fruit yields, since FYM had low micronutrient contents (Blatt, 1976; Katyal and Randhawa, 1983; May and Pritts, 1993; Pritts, 1998).

Plant population density significantly (P<0.05) increased the number and weight of berries (Table 4). The 71,111 plants/ha and 53,333 plants/ha significantly increased berry yield per hectare by 78% and 50%, respectively, compared to 40,000 plants/ha (Table 4). Results of significant PPD effect on berry yield are similar to those of Freeman (1981), Human (1999) and Legard et al. (2000), who observed increased marketable yields with increasing PPD. Similarly, Sarooshi and Cresswell (1994) recorded a 42.7% increase in fruit weight when plant density was increased from 53,500 to 93,500 plants/ha. Although production per plant was higher for the lower PPD, Freeman (1981) attributed the high yields for the higher PPD to higher plant densities. High light intensity which may have been absorbed under low PPD regime may have also reduced fruit yield as it tends to reduce flowering of strawberry (Ferree, 1988). There was no significant (P>0.05) interaction effect of FYM and PPD on number and weight of berries (Table 4). This result was attributed to the lack of a significant effect by FYM on number and weight of berries.

Farmyard manure significantly (P<0.05) affected the TSS of berries. Moderate FYM rate produced slightly lower TSS (6.6) than no FYM rate (7.2) (Table 4). This negative significant effect of FYM on TSS was attributed to the dilution of K by vigorous leaf growth induced under moderate FYM rate. Potassium promotes sugar accumulation in fruits when not diluted by vigorous vegetative growth (Marschner, 1986).

Plant population density did not have a significant (P>0.05) effect on TSS, which ranged from 6.7 to 7.0 (Table 4). On the other hand, there was a significant (P<0.05) effect of FYM and PPD interaction on TSS, which ranged from 6.5 to 7.6 (Table 4). The 40,000 plants/ha PPD and 0 t/ha FYM resulted in higher TSS than the 71,111 plants/ha and 60 t/ha FYM. This result was attributed to the significant lowering of TSS by increasing FYM rates, increased competition for the available K by the high PPD and increased dilution of K under high FYM application (Marschner, 1986).

CONCLUSIONS AND RECOMMENDATIONS

Acceptance or rejection of hypotheses tested in the present study depended on the variable under consideration. Farmyard manure and PPD either individually or in combination significantly influenced few strawberry soil characteristics such as soil CEC, Mn content, and temperature at up to 10 cm depth, which in turn probably influenced strawberry productivity and quality.

High FYM rate did not promote vegetative growth parameters of strawberry, except number of leaves. High PPD reduced vegetative growth, especially number of runners due to resource exhaustion. Increasing FYM rates reduced strawberry fruit yield and quality probably through promotion of vegetative growth at the expense of reproductive growth and potassium dilution. Low PPD on the other hand resulted in low fruit yield per hectare through reduced flowering sites and extent.

We recommended that 30 t/ha FYM be adopted where the interest is to improve soil CEC and fertility, and that FYM should be applied in combination with moderate inorganic N fertiliser to counteract nutrient imbalance and its subsequent negative effects on strawberry fruit yield. High PPD (53,333 to 71,111 plants/ha) should be adopted to realise 47% to 92% higher fruit weight in tropical climates. Further investigation on the effects of FYM should be done in the absence of factors such as black plastic mulch that can modify its impact on strawberry fruit yield in tropical climates.

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