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RESEARCH ARTICLE

LEAF TRAITS VARIATION OF ARABICA COFFEE CULTIVARS IN RESPONSE TO POPULATION DENSITY AND MINERAL NUTRIENT

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ABSTRACT

Leaf trait is good predictors of plant performance. It is closely associated with light requirement, growth and survival of the plant. This study was designed to evaluate the effect of seedling planting density and fertilizer rate on leaf traits variation of two Arabica coffee cultivars under nursery conditions. It was conducted at Jimma Agricultural Research Center from (February 29 to October 29), 2018. A factorial experiment was used and treatments were arranged using completely randomized design with three replications. Treatments consisted of combinations of two Arabica coffee cultivars (74110 and 75227), four population densities (one, two, three and four plants per polythene tube) and three compound NPK (22:6:12 + Te) rates (control, 5g and 10g). The results showed that interaction between cultivar, population density and fertilizer was significantly ($P \leq 0.05$) influenced LN, LPR and LAI, and highly significantly ($P \leq 0.01$) influenced LWR and SLA. High planting density (PD2) with 5g of NPK enhanced LN and LPR in cultivar-74110 while conventional (PD1) with 5g of NPK enhanced LN and LPR in cultivar-75227. Highest value of LWR was recorded from high planting density (PD2) with 5g of NPK while maximum value of LAI and SLA was recorded from high planting density (PD3) with 5g of NPK for both cultivars. At early field planting time, coffee seedling with higher LAI and SLA are very important for efficiently capture and better utilization of solar energy or light as well as increase seedling growth. In general, planting high population density (PD3) and fertilized with 5 g of NPK seems sufficient to improve LAI and SLA of coffee seedlings. Therefore, the future research direction should be focused on the management for increase leaf traits under field conditions.

Key words: Coffee cultivars, compound fertilizer, leaf area index, planting density, specific leaf area

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INTRODUCTION

Coffee is one of the cash crops for millions of small farmers and other actors in developing countries including Ethiopia. However, its productivity is influenced by quality of planting material, field management and fertility of the soil. *Leaf* is a part of a plant that have several *uses* and benefits to man. It is the food-making organ of plants in the process of photosynthesis. It is an important variable used to predict photosynthetic primary production, evapo -transpiration and as a reference tool for crop growth. Leaf traits are good predictors of plant performance. It is closely associated with growth, survival and light requirement of the plant (Poorter and Bongers, 2006). Pervious results indicated that morpho-physiological and chemical leaf traits vary in response to differences in shade management and nutrients (Buchanan *et al*., 2019). Light is one of the crucial factors for the growth and development of plants. Plants respond to changing light conditions by adjusting a suite of morphological and physiological traits.

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At high planting density, competition for light increase leaf weight ratio of plants (John *et al*., 2005). Higher leaf area index observed for coffee plants growing under shade indicated that these plants have higher potential for CO_2 assimilation and dry matter production, because of leaves adjust to the light environment under which they expand and develop. Increase in leaf area index with increase in plant density is important for better utilization of solar energy (Amanullah *et al*., 2008). Specific Leaf Area (SLA) is a key functional trait of plants underlying variation in growth rate. It is a major trait in leaf economics spectrum, which reflects the range of fast to slow returns on nutrient and dry mass investment in leaves (Wright *et al*., 2004; Flores *et al*., 2014). Coffee plants grown under shade or low-light develop thinner leaves, wider, a larger leaf area and higher SLA which allow more efficient capture of light energy (Poorter, 1999). These modifications allow them to efficiently capture and utilize the available light energy in order to increase their dry matter production. Coffee plants increased SLA which contributed for the higher rate of photosynthesis (Adugna *et al*., 2011). Coffee seedlings undertake certain morphological modifications and physiological adaptations for increase photosynthetic rate under high population density. In addition to genotype, water and nutrient have also make differences on leaf trait parameter. The increases of leaf traits are very important at early field establishment because it facilitate food making process by increase the efficiency of light capture, utilize light, maximize carbon gain and assimilate. Therefore, the experiment was conducted with the objective to evaluate the effect of planting density and fertilizer rate on leaf traits variation of two Arabica coffee cultivars under nursery conditions.

MATERIALS AND METHODS

Description of Experimental Area: The study was carried out at the Jimma Agricultural Research Centre (JARC) in southwestern Ethiopia under nursery for eight month from (February 29 to October 29), 2018. It is located at 7° 46' N latitude and 36° 0' E longitude and at an altitude of 1753 meter above sea level. The site receives high amount of rainfall with a mean total of 1556.9 mm per annum. Its mean minimum and maximum temperature are 12.77 and 26.14 , respectively.

Experimental Design and Treatments: The study was carried out using a factorial experiment arranged in completely randomized design with three replications. The treatments consisted of two released Arabica coffee cultivars that represent contrasting growth habits of compact (74110) and open (75227), four plant population densities (one, two, three and four plants per polythene tube) and three compound NPK rates (control, 5g and 10g). Compound NPK fertilizer (22: 06: 12 +Te) with 22% total N, 6% P_2O_5, 12% K_2O and trace elements (Te) including 4% S, 0.15% B, 0.15% Zn and 0.002% Mo was used. Hence, twenty-four treatment combinations (2*3*4) were used for the study.

Experimental Procedures: The growth medium was prepared from top soil (0-30 cm depth) from Jimma (Melko) and sand at 3:1 ratios was used. A conventional black polythene tube with size of (12 cm diameter and 22 cm length) was used and 2kg of the soil medium mix was filled, arranged on seed beds and irrigated prior to seed sowing. For each treatment, six polythene tubes were used per plot and the prepared seed from selected of coffee genotypes were sown on each polythene tube following the designed planting density. At two pair of true leaves, the compound NPK fertilizer rates were applied to each pot using ring basal method. All the routine pre-and post-sowing nursery operations including mulching, watering, shading and weed control were uniformly applied as recommended (Tesfaye *et al*., 2005).

Data Collection

Leaf Number (LN): Total number of true leaves was counted at six pairs of leaves.

Leaf Production Rate (LPR): It refers to number of leaves produced over a period of time. It was counted at two and six pairs of leaves from two plants. It was estimated as described by (Suarez, 2010). *LPR = (Ln2-Ln1)/(t2-t1), where, LPR = Leaf production rate, Ln1 and Ln2 are number of leaves produced at time t1 and t2, respectively.*

Leaf Weight Ratio (LWR): It is expressed as the dry weight of leaves to whole plant dry weight. Three polythene tubes of coffee seedlings from each treatment were used for leaf dry and plant dry and it was taken at six pair of leaves. It was estimated as described by (Kvet *et al*., 1971). *LWR = LDW/PDW, where, LWR, LDW and PDW are leaf weight ratio, leaf dry weight and plant dry weight, respectively, and expressed in* $g\ g^{-1}$.

Leaf Area Index (LAI): It was estimated as described by (Antonio *et al*., 2016 cited Oliveira and Mesquita, 2008). *LAI = RGR*(LA/PDW), where, LAI is leaf area index, RGR is relative growth rate, LA and PDW are leaf area and plant dry weight, respectively.*

Specific Leaf Area (SLA): Is the ratio of leaf area of the plant to its leaf dry weight. Three polythene tube of seedlings from each treatment for leaf dry weight and two plants for leaf area were used. It was estimated as described by (Kvet *et al*., 1971). *SLA = LA/LDW, where, SLA, LA and LDW are specific leaf area, leaf area and leaf dry weight and expressed in* cm^2g^{-1}.

Statistical Analysis: All relevant data was summarized and subjected to three way analysis of variance (ANOVA) using SAS 9.3 version (SAS, 2011). Treatment mean separation was done by least significant difference (LSD) at 5% probability level.

RESULTS

The analysis of variance revealed that the three way interaction effect of coffee genotype, population density and fertilizer rate was highly significant ($P \leq 0.01$) for LWR and SLA, whereas significant ($P \leq 0.05$) for LN, LPR and LAI (Table 1).

DISCUSION

Leaf Number and Leaf Production Rate: The result indicated that both LN and LPR were highly significantly ($P \leq 0.01$) affected by population density and fertilizer rate (Table 1). It was observed that maximum values of 11.66 and 11.33 for LN were recorded for 74110*PD2*5g of NPK and 75227*PD1*5g of NPK, respectively, while lowest values of LN was recorded from treatment combinations of 74110*PD1*10g of NPK (4) and 75227*PD1*10g of NPK (6) for cultivar-74110 and 75227. The maximum values were 191.5% and 88.8% increment in LN over lowest values in cultivar-74110 and 75227, respectively (Table 2). Similarly, treatment combinations of 74110*PD2*5g of NPK and 75227*PD1*5g of NPK resulted in maximum of LPR with the respective values of 0.094 and 0.091 which were by 394.7% and 133.3% higher than the respective lowest values (0.019 and 0.039 for 74110*PD1*10g of NPK and 75227*PD1*10g of NPK for cultivar-74110 and 75227) (Table 2). Higher values of LN and LPR were recorded for higher planting density (PD2) treated with 5g of NPK for cultivar 74110. This might be due to with adequate supply of N, which enhanced leaf growth of coffee seedlings at high planting density. This result was in agreement with some previous study indicated that adequate supply of N would promote rapid plant development through increase in number of leaves (Malavolta, 1986). Maximum values for LN and LPR were recorded for 5g of NPK in all treatment combinations, with 16.6% and 8.8% increments for LN and 20.51% and 12.34% increments for LPR over the control for cultivar-74110 and 75227, respectively.

Table 1. Summary of the ANOVA for leaf number, leaf production rate, leaf weight ratio, leaf area index and specific leaf area

SV	DF	Mean Square				
		LN	LPR	LWR	LAI	SLA
C	1	0.005^{NS}	1.1.10^{-6NS}	0.029**	1.5**	12.75*
PD	3	3.16**	3.10^{-4}**	0.011**	0.72**	746.56**
F	2	92.32**	8.7.10^{-3}**	0.012**	20.3**	5331.04**
C*PD	3	2.06*	2.10^{-4}**	5.2.10^{-3}**	0.24*	26.88**
C*F	2	2.4*	2.3.10^{-4}*	3.3.10^{-4NS}	0.077^{NS}	12.95*
PD*F	6	6.9**	6.6.10^{-4}**	7.3.10^{-3}**	0.71**	105.64**
C*PD*F	6	1.15*	1.1.10^{-4}*	4.6.10^{-3}**	0.15*	10.43**
Error	46	0.49	4.5.10^{-5}	1.2.10^{-3}	0.06	2.98
CV (%)		7.56	9.6	7.4	13.52	1.1

*SV, DF, C, PD, F, *,** and NS represents source of variation, degree of freedom, cultivars, population densities, fertilizer rates, significant at ($P \leq 0.05$), highly significant at ($P \leq 0.01$) and non significant, respectively.*

Table 2. Effect of coffee cultivar, population density and fertilizer rate on leaf number and leaf production rate of coffee seedlings

NPK (g)	Cultivar-74110				Cultivar-75227			
	PD1	PD2	PD3	PD4	PD1	PD2	PD3	PD4
				Leaf Number				
0	10.33^{a-f}	10^{b-f}	10^{b-f}	9.16^{e-h}	10.33^{a-f}	9.5^{d-g}	9.66^{c-g}	8.6^{ghi}
5	11.33^{ab}	11.66^{a}	10.9^{abc}	10.7^{a-d}	11.33^{ab}	11^{abc}	10.433^{a-e}	10.43^{a-e}
10	4.00^{k}	9.00^{f-i}	6.00^{j}	8.00^{hi}	6.00^{j}	8.00^{hi}	8.33^{ghi}	7.66^{i}
LSD (%)								1.38
CV (%)								7.56
				Leaf Production Rate				
0	0.081^{a-f}	0.078^{b-f}	0.077^{b-f}	0.069^{e-h}	0.081^{a-f}	0.073^{d-g}	0.075^{c-g}	0.064^{ghi}
5	0.091^{ab}	0.094^{a}	0.086^{a-d}	0.084^{a-d}	0.091^{ab}	0.087^{abc}	0.082^{a-e}	0.0816^{a-e}
10	0.019^{k}	0.068^{f-i}	0.039^{j}	0.058^{hi}	0.039^{j}	0.058^{hi}	0.061^{ghi}	0.055^{i}
LSD (%)								0.013
CV (%)								9.6

Figures followed by same letters within a column and row for a given variable are not significantly different at 5% probability level. Where, PD1, PD2, PD3 and PD4 represent population density 1, 2, 3 and 4, respectively.

Table 3. Effect of coffee cultivar, population density and fertilizer rate on leaf weight ratio, leaf area index and specific leaf area of coffee seedlings

NPK (g)	Cultivar-74110				Cultivar-75227			
	PD1	PD2	PD3	PD4	PD1	PD2	PD3	PD4
				Leaf Weight Ratio				
0	0.409^{h-k}	0.467^{e-h}	0.387^{j-m}	0.39^{jkl}	0.49^{c-g}	0.44^{g-j}	0.458^{e-i}	0.405^{i-l}
5	0.514^{b-e}	0.545^{a-d}	0.542^{a-d}	0.51^{cde}	0.548^{a-d}	0.593^{a}	0.57^{ab}	0.55^{abc}
10	0.33^{m}	0.489^{d-g}	0.41^{h-k}	0.356^{klm}	0.34^{lm}	0.45^{f-j}	0.49^{d-g}	0.5^{c-f}
LSD (%)								0.062
CV (%)								7.4
			Leaf Area Index					
0	1.49^{c-f}	1.71^{cd}	1.13^{efg}	0.98^{fgh}	1.86^{cd}	1.34^{d-g}	1.67^{cd}	1.11^{fg}
5	2.61^{b}	2.8^{ab}	2.88^{ab}	2.53^{b}	2.67^{b}	2.7^{b}	3.32^{a}	3.3^{a}
10	0.43^{i}	1.13^{efg}	1.33^{d-g}	0.91^{ghi}	0.49^{hi}	1.65^{c-f}	1.9^{c}	1.34^{d-g}
LSD (%)								0.53
CV (%)								13.5
				Specific Leaf Area ($cm^2 g^{-1}$)				
0	161.4^{ij}	164.77^{hi}	165.17^{ghi}	169.47^{ghi}	157.43^{jk}	163.13^{i}	166.3^{f-i}	168.77^{fgh}
5	170.73^{efg}	174.833^{cde}	186.933^{a}	180.77^{b}	170.733^{def}	175.97^{bcd}	191.77^{a}	177.53^{bc}
10	139.8^{m}	150.77^{l}	154.1^{kl}	154.667^{kl}	131.73^{n}	150.77^{kl}	154.44^{kl}	155.03^{kl}
LSD (%)								5.24
CV (%)								1.1

Figures followed by same letters within a column and row for a given variable are not significantly different at 5% probability level. PD1, PD2, PD3 and PD4 represent population density 1, 2, 3 and 4, respectively.

Table 4. Mean comparison of main factors of cultivars, population densities and fertilizer rates on LN, LPR, LWR, LAI and SLA

Main Factors		Parameters				
		LN	LPR	LWR	LAI	SLA
Cultivars	74110	9.26^{a}	0.07^{a}	0.445^{b}	1.66^{b}	164.4^{a}
	75227	9.28^{a}	0.071^{a}	0.486^{a}	1.95^{a}	163.6^{b}
LSD (5%)		0.33	0.0032	0.016	0.116	0.82
Population Densities	PD1	8.89^{b}	0.067^{b}	0.44^{b}	1.59^{b}	155.2^{d}
	PD2	9.86^{a}	0.076^{a}	0.496^{a}	1.86^{a}	163.3c
	PD3	9.22^{b}	0.07^{b}	0.48^{a}	2.04^{a}	169.8^{a}
	PD4	9.09^{b}	0.069^{b}	0.45^{b}	1.69^{b}	167.7^{b}
LSD (5%)		0.47	0.0045	0.023	0.164	1.16
Fertilizer Rates	0	9.7^{b}	0.075^{b}	0.43^{b}	1.41^{b}	164.6^{b}
	5g NPK	10.96^{a}	0.087^{a}	0.545^{a}	2.86^{a}	178.6^{a}
	10g NPK	7.13^{c}	0.049^{c}	0.421^{b}	1.15^{c}	148.8^{c}
LSD (5%)		0.41	0.039	0.02	0.142	1.0
CV (%)		7.56	9.6	7.4	13.52	1.1

Figures followed by same letters within a column for each factors are not significantly different at 5% probability level. Where, PD1, PD2, PD3 and PD4 represent population density 1, 2, 3 and 4, respectively.

Leaf Weight Ratio: The result revealed that LWR was highly significantly ($P \leq 0.01$) influenced by coffee cultivar, population density and fertilizer rate (Table 1), where maximum value (0.545 g g^{-1}) of LWR was recorded for 74110*PD2*5g of NPK and the minimum value of (0.33 g g^{-1}) for 74110*PD1*10g of NPK for cultivar-74110. Similarly, maximum value (0.59 g g^{-1}) of LWR was recorded for 75227*PD2*5g of NPK, whereas the minimum (0.34 g g^{-1}) for 75227*PD1*10g of NPK for cultivar-75227 (Table 3). The maximum values were exhibited 65.2% and 73.5% higher LWR than their respective lowest values for cultivar-74110 and 75227, respectively. Higher LWR with higher planting density rather than with the single seedling in polythene tube might be related to competition for light with more dry matter accumulation in the leaves. Application of 5g of NPK resulted in 16.7% and 34.77% higher LWR over the control, and 11.45% and 31.77% higher values over the plots treated with 10g of NPK for cultivar-74110 and 75227, respectively. High LWR means partitioning of a large proportion of biomass to leaves (John *et al*., 2005). In higher population density a higher LWR and SLA may improve competitive ability of species (Hendrik, 2016). The result of the present study was also in agreement with the findings of Poorter (1999) who reported that plants shaded by other trees produce thinner, larger and wider leaves and have higher LWR than un-shaded plants.

Leaf Area Index: LAI was highly significantly ($P \leq 0.01$) affected by coffee cultivar, population density and fertilizer rate (Table 1), where the highest values of 2.88 and 3.32 were recorded for 74110*PD3*5g of NPK and 75227*PD3*5g of NPK for cultivar-74110 and 75227, respectively, respectively (Table 3). It was 569.85% and 577.55% higher than the respective lowest values for cultivar-74110 and 75227, respectively. The differences in LAI of cultivars might be related with variations in morphological growth habit, due to genotypic differences (Mohammed *et al*., 2015). This results in line with Sobrado (2005) who reported that the diversified growth habits of Arabica coffee genotypes influence LAI. Leaf is an important source in manufacturing photo assimilates and an increase in LAI results in better utilization of solar energy and enhanced growth of coffee seedlings. Higher LAI was recorded for high planting density (PD3) with 5g of NPK for both cultivars, with 10.34% to 24.34% increment over single seedling (PD1), which might related with production of more leave area with increasing seedling number. Application of 5g of NPK more enhanced LAI than the other fertilizer treatments; as N increases vegetative growth especially number of leaves and leaf area, and resulted in 154.8% and 98.8% higher LAI over the control, and it was decreased by 53.8% and 42.8% with application of 10g of NPK to cultivar-74110 and 75227, respectively. This might be related with toxicity problems with excess amount of fertilizer. The highest LAI was recorded from main factors of population density3 (PD3) due to mutual shading and 5g of NPK (Table 4). Optimum LAI is very important, as both below and above the critical level may not allowed maximum light interception by plants and yield may even tend to decline due to shading and competition for water, nutrients and light (Taye and Burkhardt, 2015).

Specific Leaf Area: The result indicated that SLA was significantly ($P \leq 0.05$) affected by coffee cultivar, were also highly significantly ($P \leq 0.01$) for SLA difference due to population density and fertilizer rate (Table 1). It was observed that maximum value (186.93 cm^2 g^{-1}) of SLA was recorded for 74110*PD3*5g of NPK, whereas the minimum value (139.8 cm^2 g^{-1}) was recorded for 74110*PD1*10g of NPK for cultivar-74110. Similarly, the highest of (191.77 cm^2 g^{-1}) SLA was recorded for cultivar-75227 with PD3 and 5g of NPK, whereas the lowest value (131.73 cm^2 g^{-1}) was recorded for combination of 75227*PD1*10g of NPK for cultivar-75227 (Table 3). High planting density increased SLA, which was more enhanced with application of 5g of NPK that resulted in 13.17% and 15.3% increments over the control and 21.3% and 24.2% increments over 10g of NPK for cultivar-74110 and 75227, respectively. The highest SLA was recorded from main factors of population density3 (PD3) due to mutual shading and 5g of NPK (Table 4). High planting density increase SLA, might be related to the tendency of plants to efficient utilized the limited light penetrating through the canopy due to mutual shading. It could be also attributed to morphological modification of plants growing under shade to adapt to available low light intensity (Hiwot, 2011). Similarly, it has been reported that plants shaded by other trees produce larger, thinner and wider leaves, and have higher SLA (Poorter, 1999). Coffee plants grown under shade develop thinner leaves and a larger leaf area which allow more efficient capture of light energy. At low light, plants increase light interception by means of a high biomass allocation to leaves and formation of thin leaves with a high SLA. Both SLA and LAI may vary with light intensity, as higher SLA has been observed for plant under low light condition (Taye, 2006). This modification allows them to efficiently capture and utilize the available light energy in order to increase their dry matter production (Li *et al*., 2005).

Summary and Conclusion

Leaf traits are good predictors of plant performance. It is closely associated with growth, survival and light requirement of the plant. Result indicated that there was significant increase in LN and LPR due to planting density in cultivar-74110, whereas sowing one seed per polyethylene tube and fertilized with 5g of NPK promote LN and LPR in cultivar-75227. Maximum value of LWR was recorded from sowing two seeds per polythene tube and fertilized with 5g of NPK in both cultivars. It was observed that sowing three seeds per polythene tube and fertilized with 5g of NPK was significantly increased LAI and SLA in both cultivars, but, higher increments was observed in cultivar-75227. In general, at early field transplanting stage a seedling with larger leaf traits are important for capture and utilize light as well as potential for CO_2 assimilation and faster growth rate; sowing three seeds per polythene tube and fertilized with 5g of NPK was enhanced LAI and SLA of coffee seedlings in both cultivars. Therefore, the future research direction should be focused on management to increase the coffee leaf traits for efficient utilization of light under field conditions.

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