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Effect of seedling fibrous roots on field performance of hybrid coffee varieties

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The objective of this study was to evaluate the effect of number of fibrous roots per seedling on plant growth and yield components of hybrid coffee varieties. A split plot experiment in a randomized complete block design (RCBD) with three replications was used. The main factor consisted of five varieties (N39-2, N39-3, N39-7, KP423-1 and KP423-2) whereas the sub-factor consisted of four types of roots (seedlings with 1-9 fibrous roots; seedlings with 10-17 fibrous roots; seedlings with ≥ 18 fibrous roots and control). Plants were evaluated for vegetative growth and yield components 14 months from the date of planting. The data were subjected to analysis of variance using CoStat software version 6.311 and treatment means were separated based on Tukey's test at P ≤ 0.05. Results indicate that coffee varieties N39-3, KP423-1 and KP423-2 were significantly (P = 0.00) taller than varieties N39-1 and N39-7 while coffee variety N39-2 significantly produced a larger number of fruit clusters per plant (P = 0.00) and higher seed yield (P = 0.00) than the rest of coffee varieties. Results also show that seedlings with at least 18 fibrous roots per seedling highly significantly increased plant height (P = 0.00), stem internode length (P = 0.00), number of fruit bearing primaries per plant (P = 0.00), number of fruit clusters per plant (P = 0.00), number of berries per plant (P = 0.00) and total seed yield (P = 0.00) of hybrid coffee varieties. The interactions between variety N39-3 and seedlings with at least 18 fibrous roots per seedling only significantly increased (P = 0.00) the internode length compared with the interaction between variety N39-3 and seedlings with 10-17 fibrous roots per seedling, and variety KP423-2 and seedlings with 1-9 fibrous roots per seedling. It is concluded that coffee growers should use seedlings with at least 18 fibrous roots per seedling in order to increase plant growth and total seed yield of improved hybrid coffee varieties. Further studies are required to determine propagation technologies which can increase the number of fibrous roots to at least 18 per stem cutting of hybrid coffee varieties.

Key words: Fibrous roots, number of bearing primary branches, number of clusters, plant growth, seed weight, total seed yield.

INTRODUCTION

Seedlings establishment and survival in the field is a function of seedling root and shoot biomass (Johansson et al., 2012; Corpuz et al., 2013). Below and above ground plant growth traits have been used to predict the success of field establishment of seedlings and their subsequent field performance (Wightman, 1999; Davis and Jacobs, 2005; Mohamed, 2013). Root biomass, especially the number of roots and root length, is directly related to establish and survive in the field after transplanting as well as plant height and basal diameter

(Wightman, 1999; Amri et al., 2009); Mohamed, 2013). Research has shown that the ability of crops to absorb water and nutrients is associated with the number and length of roots as well as number of leaves, leaf size, plant height and stem diameter (Hong et al., 2012). Generally, seedlings propagated by stem cuttings have been reported to have shallower roots with branchy stems when established in the field (Longman, 1993). A study by Çiçek et al. (2010) found that seedlings propagated by cuttings of *Fraxinus angustifolia* performed better in the field after transplanting than those propagated by seeds.

Tanzania Coffee Research Institute (TaCRI) released 19 hybrid Arabica coffee varieties that are established early in the field, heavy feeders and produce high yield of up to 3 t/ha against 1.5 t/ha of the traditional coffee varieties (Teri et al., 2011). High plant growth and yield are function of better root and shoot systems with the former enhancing more nutrient and water uptake from the soil (Fitch et al., 2005). There are limited reports on the effect of root systems on growth and yield of improved hybrid coffee varieties developed by TaCRI. The objective of this study was to evaluate the effect of fibrous roots on plant growth and yield components of improved hybrid coffee varieties.

MATERIALS AND METHODS

Description of the study area

The field experiment was set up from July 2014 to December 2016 at TaCRI. The station is located at Lyamungu, Moshi Tanzania at latitude of 03º14.699' S and longitude of 037º14.762'E with a mean altitude of 1268 m a.s.l. The soil is classified as Nitisol with a pH ranging from 4.8 to 5.7 and the climate is classified as tropical with warm-dry (August to February) and rainy (March to June) seasons with an average annual rainfall of about 1250 mm. During the study, the mean temperature from July 2014 December in 2016 was 28.34°C with the lowest temperature of 28.23 in 2014 and highest temperatures of 29.25°C in 2016.

Seedling production

Coffee stem cuttings were raised in a mixture of forest soil and fine sand at ratio of 2:1 (v/v). The number of laterals and fibrous roots of stem cuttings were counted four months from the date of planting to establish four groups of seedlings as recommended by Rouhani et al. (1987). Group 1 consisted of seedlings with 1-9 fibrous roots and 1-4 lateral roots; Group 2 seedlings with 10-17 fibrous and 1-4 lateral roots; Group 3 seedlings with ≥18 fibrous and 1-4 lateral roots; and Group 4 seedlings with unsorted roots as control. The seedlings with grouped roots were transplanted or potted into black polythene tubes with diameter of 15 cm and height of 15 cm. The growth media consisted of top forest soil and fine sand as above supplemented with N-P-K fertilizer (20: 10: 10) at a rate of 33.3 g/m^3. The polytubes were filled two-third with the growth media. The seedlings were placed under a black shade net absorbing 30% of solar radiation. Water soluble fertilizer (poly-feed) containing 19N-19P-19K+Zn, B, Fe, Mn, Cu, Mo at a rate of 150 g/15 L was sprayed on the seedlings using knapsack sprayer three weeks after transplanting.

Land preparation and soil analysis

Land preparation was carried out by ploughing to a depth of 20 cm and harrowing as recommended by Cambrony (1992). Two blocks were established in the experimental area for soil sampling based on land topography and these were categorized as block 1 and 2. Soil samples were collected in three sites in each block using a hand-auger from depths of 0-30 cm and 30-60 cm. Composite samples were prepared to get representative samples in each site as recommended by Nunez et al. (2011) and Bekeko (2014). Separate soil core samples were also collected from the three sites with metal cores forced manually into the soil for determination of bulk density and soil moisture content. The collected soil samples were analysed at Lyamungu Soil Laboratory. Samples were air-dried, ground, sieved through 2 mm sieve as recommended by Nunez et al. (2011). Results show that the soil was sandy loam with a bulk density of 1.27 g/cm^3. Results of chemical properties of the soil are shown in Table 1. Remarks on the level of nutrients were based on FAO (1984) and Landon (1991).

Experimental design

A split-plot experiment in a randomized complete block design replicated three times was used. The main factor was five coffee varieties (N39-2; N39-3; N39-7; KP423-1 and KP423-2) whereas the sub-plot factor consisted of four seedling root groups (Group 1: seedlings with 1 - 9 fibrous roots and 1- 4 lateral roots, Group 2: seedlings with 10-17 fibrous and 1- 4 lateral roots, Group 3: seedlings with ≥ 18 fibrous and 1 - 4 lateral roots and Group 4: seedlings with unsorted roots as control). The treatments were randomized in both main and sub-plots within each replication according to Kuehl (2000) using Gen Stat discovery Edition 3 software.

Seedling planting and management

The seedlings were transplanted in the field in July 2014 at a depth of 60 × 60 cm holes and spacing between and within rows of 2.74 × 2.74 m and between blocks of 3 m as recommended by TaCRI (2011). A border row of the same coffee varieties was planted around the experimental area to overcome border effects on the experimental units as recommended by Tesso et al. (2011). The total number of rows was 20 each comprising 8 plants for each variety and each root characteristic. The total number of experimental units per replication was 160 whereas the plot size was 1,321.2 m^2. Based on soil analysis results, 18 kg of well decomposed farm yard manure per planting hole was incorporated with the top soil one month before planting as recommended by TaCRI (2011) and Marandu et al. (2004).

Fertilizer N.P.K containing 20% N, 10% P and 10% K was

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Table 1. Soil chemical characteristics of area planted with coffee.

Chemical properties	Analysis method	Results
pH	1:2.5 soil: water ratio	5.15[a]
Electric conductivity (dS m^{-1})	1:2.5 soil: water ratio	1.40[a]
CEC ($cmol_{(+)}kg^{-1}$)	Ammonium acetate saturation	4.41[a]
Exchangeable Ca ($cmol_{(+)}kg^{-1}$)	Atomic absorption spectrometry	3.26[b]
Exchangeable Mg ($cmol_{(+)}kg^{-1}$)	Atomic absorption spectrometry	0.45[b]
Exchangeable K ($cmol_{(+)}kg^{-1}$)	Flame photometry	0.43[c]
Exchangeable Na ($cmol_{(+)}kg^{-1}$)	Flame photometry	0.05[a]
Available P (mg kg^{-1})	Bray and Kurtz 1	19.71[c]
Organic Carbon %	Walkley and Black	0.50[a]
Total N%	Semi micro Kjeldahl	0.03[a]
C: N ratio		21.09[b]

a = Very low, b = Low, c = Medium and d = High.
Source: FAO (1984) and Landon (1991).

applied at a rate of 100 g/plant during transplanting. Urea containing 46% N was applied one month from the date of transplanting at rate of 50 g/plant while N:P:K was again applied at a rate of 50 g/plant during the short rains six months from the date of transplanting. Furthermore, N:P:K (20:10:10) at a rate of 100 g per plant was applied four months before flowering as side dressing during the long rains in May 2015. One month after full flowering, calcium ammonium nitrate (CAN) containing 27% nitrogen, 13.5% ammonia, 13.5% nitrate, 4.0% magnesium and 6.0% calcium was applied as side dressing at a rate of 200 g/plant. Water soluble fertilizer (poly-feed) containing 19N-19P-19K+Zn, B, Fe, Mn, Cu, Mo at a rate of 150 g/15 L of water was sprayed using knapsack sprayer twice after 100% fruiting. N.P.K containing 20%N, 10%P and 10% K at a rate of 200 g/plant was applied as side dressing. Irrigation when needed was done by furrow. Agronomic practices such as weeding, insect and pest control were carried out as recommended by TaCRI (2011).

Data collection

Data on all the variables except for days to 50% flowering were collected from six central inner plants in each row as recommended by Tefera et al. (2016).

Plant growth traits

Days to flowering was measured on a plot basis as the number of days from the date of transplanting to when approximately 50% of the plants in a plot produced flowers (Assis et al., 2014; Tefera et al., 2016). The plant height was measured at full fruit bearing (22 months after transplanting) from the base of the stem to the plant apex using graduated ruler (Assis et al., 2014; Tefera et al., 2016). The stem diameter of the main stem was measured at full fruit bearing at 5 cm above the ground using Vernier Calliper (Assis et al., 2014; Tefera et al., 2016). The length of bearing primary branches was measured from the point of attachment to the main stem to the apex using graduated ruler as an average value of four longest bearing primaries per plant (Esther and Adomako, 2010). The length of internodes was measured using graduated ruler as an average value of four internodes per plant (Esther and Adomako, 2010). Total number of bearing primary branches was estimated by counting the total number of bearing primaries per plant at full fruit bearing stage (Esther and Adomako, 2010).

Yield and yield components

Number of clusters or number of fruiting nodes was determined as an average number of clusters per plant from four heavily bearing primaries at the middle across all directions (Etienne and Betrand, 2001). The number of berries or fruits was estimated as an average number of berries per plant counted from the four heavily bearing primaries at the middle across all directions as recommended by Etienne and Betrand (2001). Yield was obtained by harvesting mature red cherries to get fresh weight per plot using gravimetric scale. Transformation of cherry weight to clean coffee weight was done using the conversion factor of 0.16 for Arabica coffee as recommended by ICO (2011). Seed weight was measured using gravimetric scale from 100 cherries taken randomly from each plot during the 7th harvest (peak yield) and then converted to parchment using conversion factor of 0.16 for Arabica (Agbaje et al., 2011).

Data analysis

Data collected were subjected to analysis of variance (ANOVA) using CoStat software version 6.311 and declared significant at P≤0.05 using the following statistical model for the spilt-plot design as described by Kuehl (2002):

$$Yi_{ijk} = \mu + \alpha_i + P_k + d_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}.$$

where μ = the general error mean; $\alpha_{i\,i}$ = the effect of the ith level of factor; P_k = the effect of the kth block; d_{ik} = the whole-plot random error; β_j = effect of the jth level of factor B, $(\alpha\beta)_{ij}$ = the interaction effect between factors A and B; ε_{ijk} = is the sub-plot random error.
The differences between the treatment means were separated based on Tukey's test at a probability of 5%.

RESULTS

Effect of hybrid coffee varieties on plant growth traits

Results indicate that coffee varieties highly significantly (P = 0.00) affected plant height and significantly (P = 0.02) affected the length of bearing primaries (Table 2).

However, the stem diameter (P = 0.56), length of

Table 2. Effect of hybrid coffee varieties on plant growth traits.

Varieties	Plant height (cm)	Main stem diameter (cm)	Plant internode length (cm)	Length of primaries (cm)	Days to 50% flowering
N39-2	201.32[b]	3.61	6.08	106.53[a]	473.00
N39-3	214.43[a]	3.68	6.09	103.60[ab]	473.00
N39-7	198.31[b]	3.56	6.18	98.05[ab]	473.91
KP423-1	207.74[a]	3.55	6.14	98.21[ab]	473.00
KP423-2	217.46[a]	3.59	6.24	87.37[b]	472.82
Mean	207.85	3.60	6.14	98.75	472.95
CV (%)	3.49	6.12	19.38	12.09	0.06
P-values	0.00	0.56	0.99	0.03	0.59

Means followed by the same letter in the same column are not significantly different at P≤0.05 according to Tukey's Test.

Table 3. Effect of number of fibrous roots on plant growth traits.

Root characteristics	Plant height (cm)	Main stem diameter (cm)	Plant internode length (cm)	Length of primaries (cm)	Days to 50% flowering
Group one (1-9 roots/seedling)	206.25[b]	3.47[b]	5.71[b]	86.32[b]	472.86[a]
Group two (10-17 roots/seedling)	203.42[b]	3.53[ab]	5.84[b]	102.85[a]	472.93[a]
Group three (≥18 roots/seedling)	218.24[a]	3.75[a]	6.96[a]	105.92[a]	473.00[a]
Group four (control)	203.50[b]	3.62[ab]	6.07[b]	99.94[a]	473.00[a]
Mean	207.85	3.59	6.14	98.75	472.95
CV (%)	5.06	6.68	10.74	10.85	0.04
P-values	0.00	0.02	0.00	0.00	0.21

Means followed by the same letter in the same column are not significantly different at P≤0.05 according to Tukey's Test.

internodes (P = 0.99) and the number of days to 50% flowering (P = 0.59) were not significantly affected by coffee varieties.

Effect of number of roots on plant growth traits of hybrid coffee varieties

The number of fibrous roots per seedling highly significant (P = 0.00) affected coffee plant height, length of primaries and length of internodes, and significantly (P = 0.02) affected stem diameter (Table 3). However, the number of days to 50% flowering was not significantly (P = 0.21) affected by number of fibrous roots per seedling.

Interaction effect of coffee varieties and number of roots on plant growth traits

Interaction effect between varieties and number of roots per seedling significantly (P=0.05) affected internode length (Table 4). However, plant height (P = 0.14), stem diameter (P = 0.19) and length of primaries (P = 0.21) and days to 50% flowering (P = 0.85) were not significantly affected by the interaction between varieties and root characteristics.

Effect of hybrid coffee varieties on yield and yield components

Coffee varieties highly significantly (P = 0.00) affected seed yield and number of fruit clusters per plant and significantly affected the number of bearing primaries (P = 0.02) and number of berries per plant (P = 0.01) (Table 5). However, seed weight was not significantly (P = 0.43) affected by varieties.

Effect of number of roots on yield and yield components

The number of fibrous roots per seedlings highly significant (P = 0.00) affected seed yield, seed weight, number of bearing primaries, number of fruit clusters and number of berries per plant (Table 6).

Interaction effect of hybrid coffee varieties and number of roots on yield and yield components

Interaction between varieties and number of fibrous roots

Table 4. Effect of interaction between hybrid coffee varieties and root characteristics on plant vegetative morphological characteristics.

Varieties × Root characteristics	Plant height (cm)	Main stem diameter (cm)	Length of primaries (cm)	Internode length (cm)	Days to 50% flowering
N39-2 x 1-9 roots/seedling	195.00	3.47	102.86	6.00^{a-c}	473.00
N39-2 x 10-17 roots/seedling	201.44	3.70	114.63	5.92^{a-c}	473.00
N39-2 x ≥ 18 roots/seedling	213.96	3.63	116.46	6.60^{a-c}	473.00
N39-2 x control	194.90	3.64	92.16	5.81^{a-c}	473.00
N39-3 x 1-9 roots/seedling	210.00	3.53	90.63	5.73^{a-c}	473.00
N39-3 x 10-17 roots/seedling	217.70	3.84	109.20	5.47^{bc}	473.00
N39-3 x ≥ 18 roots/seedling	221.66	3.68	112.43	7.62^{a}	473.00
N39-3 x control	208.38	3.67	102.16	5.56^{a-c}	473.00
N39-7 x 1-9 roots/seedling	194.66	3.46	82.96	5.77^{a-c}	472.66
N39-7 x 10-17 roots/seedling	191.49	3.42	102.77	5.57^{a-c}	473.00
N39-7 x ≥ 18 roots/seedling	222.11	4.01	107.00	6.88^{ab}	473.00
N39-7 x control	185.00	3.36	99.50	6.50^{a-c}	473.00
KP423-1 x 1-9 roots/seedling	208.72	3.36	82.10	6.29^{a-c}	473.00
KP423-1 x 10-17 roots/seedling	197.11	3.31	102.70	5.99^{a-c}	473.00
KP423-1 x ≥18 roots/seedling	210.93	3.74	104.36	6.40^{a-c}	473.00
KP423-1 x control	214.22	3.71	103.70	5.88^{a-c}	473.00
KP423-2 x 1-9 roots/seedling	222.91	3.53	73.03	4.77^{c}	472.66
KP423-2 x 10-17 roots/seedling	209.39	3.37	84.96	6.28^{a-c}	472.66
KP423-2 x ≥18 roots/seedling	222.55	3.70	89.33	7.31^{ab}	473.00
KP423-2 x control	214.99	3.70	102.16	6.59^{a-c}	473.00
Mean	207.85	3.59	98.75	6.14	472.95
CV%	5.06	6.68	10.85	6.14	0.04
P-values	0.14	0.19	0.21	0.05	0.85

Means followed by the same letter in the same column are not significantly different at P≤0.05 according to Tukey's Test.

Table 5. Effect of hybrid coffee varieties on yield and yield components.

Varieties	No. of bearing primaries	No. of fruit clusters/plant	No. of berries/plant	100 seed weight (g)	Seed yield (t/ha)
N39-2	38.93^{a}	12.27^{a}	88.15^{a}	13.59^{a}	2.28^{a}
N39-3	37.05^{ab}	10.85^{b}	78.95^{ab}	14.16^{a}	1.90^{ab}
N39-7	34.67^{b}	10.53^{b}	71.57^{ab}	13.18^{a}	1.22^{c}
KP423-1	35.35^{ab}	10.66^{b}	75.18^{ab}	14.54^{a}	1.43^{bc}
KP423-2	34.28^{b}	9.60^{c}	59.63^{b}	14.25^{a}	1.08^{c}
Mean	36.06	10.78	74.69	13.95	1.58
CV (%)	8.09	5.65	18.40	13.18	29.11
P-values	0.02	0.00	0.01	0.43	0.00

Means followed by the same letter in the same column are not significantly different at P≤0.05 according to Tukey's Test.

per seedling highly significantly (P=0.00) affected number of bearing primaries and seed yield, and significantly (P = 0.01) affected 100 seed weight (Table 7). However, the number of fruit clusters per plant (P = 0.89) and number of berries per plant (P = 0.63) were not affected by the interaction between varieties and root characteristics.

DISCUSSION

Effects of varieties on vegetative growth components

The five hybrid coffee varieties differed in their plant and primary branch height where variety N39-3, KP423-1 and

Table 6. Effect of number of roots on yield and yield components.

Number of roots per seedling	No. of bearing primaries	No. of clusters/plant	No. of berries/plant	100 seed weight (g)	Seed yield (t/ha)
Group one (1-9 roots/seedling)	34.69^{b}	10.06^{b}	68.38^{b}	14.74^{a}	1.06^{c}
Group two (10-17 roots/seedling)	35.54^{b}	10.32^{b}	72.77^{b}	13.95^{ab}	1.43^{b}
Group three (≥18 roots/seedling)	38.86^{a}	12.46^{a}	90.98^{a}	13.35^{b}	2.61^{a}
Group four (control)	35.14^{b}	10.28^{b}	66.64^{b}	13.74^{b}	1.24^{bc}
Mean	36.06	10.78	74.69	13.95	1.58
CV (%)	6.60	11.22	17.21	6.81	20.33
P-values	0.00	0.00	0.00	0.00	0.00

Means followed by the same letter in the same column are not significantly different at P≤0.05 according to Tukey's Test.

Table 7. Interaction effects between hybrid coffee varieties and number of roots on yield and yield components.

Varieties x number of roots	No. of bearing primaries	No. of clusters/plant	No. of berries/plant	100 seed weight (g)	Seed yield (t/ha)
N39-2 x1-9 roots/seedling)	45.70^{a}	10.76^{b}	84.20^{a-d}	14.52^{ab}	1.02^{d}
N39-2 x 10-17 roots/seedling	39.00^{a-d}	12.10^{ab}	90.83^{a-c}	13.94^{a-c}	2.77^{ab}
N39-2 x ≥ 18 roots/seedling	35.80^{b-d}	14.66^{a}	111.63^{a}	12.88^{a-c}	3.69^{a}
N39-2 x control	36.60^{b-d}	11.56^{ab}	91.60^{a-c}	13.02^{a-c}	1.64^{cd}
N39-3 x 1-9 roots/seedling	37.50^{b-d}	10.13^{b}	74.26^{a-d}	14.39^{a-c}	1.11^{d}
N39-3 x10-17 roots/seedling	41.00^{a-c}	10.13^{b}	79.43^{a-d}	14.20^{a-c}	1.61^{cd}
N39-3 x ≥ 18 roots/seedling	39.50^{a-d}	12.36^{ab}	95.63^{ab}	14.31^{a-c}	3.72^{a}
N39-3 x control	40.70^{a-d}	10.76^{b}	74.80^{a-d}	13.75^{a-c}	1.14^{d}
N39-7 x 1-9 roots/seedling	37.80^{b-d}	10.03^{b}	71.76^{b-d}	13.75^{a-c}	1.01^{d}
N39-7 x 10-17 roots/seedling	34.0^{cd}	9.66^{b}	65.03^{b-d}	13.76^{a-c}	1.01^{d}
N39-7 x ≥ 18 roots/seedling	42.00^{ab}	12.13^{ab}	77.96^{a-d}	11.38^{c}	1.77^{b-d}
N39-7 x control	39.00^{a-d}	10.30^{b}	71.53^{b-d}	13.86^{abc}	1.08^{d}
KP423-1 x 1-9 roots/seedling	42.00^{ab}	9.83^{b}	54.83^{cd}	15.23^{ab}	1.15^{d}
KP423-1 x 10-17 roots/seedling	37.70^{bcd}	10.73^{b}	73.16^{bcd}	15.30^{ab}	0.91^{d}
KP423-1 x ≥18 roots/seedling	36.40^{b-d}	12.36^{ab}	84.93^{a-d}	14.43^{ab}	2.30^{bc}
KP423-1 x control	36.30^{b-d}	9.73^{b}	52.26^{d}	13.19^{abc}	1.35^{cd}
KP423-2 x 1-9 roots/seedling	37.50^{bcd}	9.53^{b}	70.86^{b-d}	15.83^{a}	1.01^{d}
KP423-2 x 10-17 roots/seedling	36.70^{b-d}	9.00^{b}	78.83^{a-d}	12.55^{bc}	0.83^{d}
KP423-2 x ≥18 roots/seedling	33.30^{d}	10.80^{b}	86.33^{a-d}	13.74^{a-c}	1.54^{cd}
KP423-2 x control	34.30^{cd}	9.07^{b}	81.36^{a-d}	14.91^{ab}	0.94^{d}
Mean	36.06	10.78	78.56	13.95	1.58
CV%	6.6	11.22	15.3	6.81	20.25
P-values	0.00	0.89	0.63	0.01	0.000

Means followed by the same letter in the same column are not significantly different at P≤0.05 according to Tukey's Test.

KP423-2 were the tallest followed by variety N39-2 and N39-7 with shortest stems. High stem height increased amounts of water soluble carbohydrate reserves and enhanced plant growth in wheat genotypes (Ehdaie et al., 2006). Similarly, stem carbohydrate reserves account for 20 and 70% of the final plant weight under non-stressed and water stressed conditions, respectively and 20-40% of the total yield in wheat crop (Liw et al., 2015; Kumar et al., 2017). Stored water soluble carbohydrates also maintained a steady growth and accounts for more than 40% of the stem dry weight in rape seed (Li et al., 2015). Carbohydrate reserves are also associated with plant response to the environmental conditions. Plants with high carbohydrate and mineral nutrient reserves are more resilient to stressful environmental conditions as reported in Robusta coffee (*Coffea canephora*) and hardwood tree Alder (*Alnus* spp) (Rezende et al., 2010; Pijut et al., 2011).

Effects of number of roots on coffee yield and yield components

Results from this study show that the number of fibrous roots per seedling increased yield components and therefore total seed yield of hybrid coffee varieties. The observed higher seed yield from coffee plants with the largest number of fibrous roots is associated with increased nutrient and water uptake. Previous studies have also associated yield with the ability of plants to absorb water and nutrients (Hong et al., 2012). Root traits have been used to predict the success of field establishment of seedlings and their subsequence field performance (Davis and Jacobs, 2005). Similarly, root biomass was significantly and positively correlated with yield in 12 peanut varieties (Hong et al., 2012). Atta et al. (2013) also noted a stronger relationship between root and above ground traits with root traits contributing 30-45% of the total variation in water use efficiency and grain yield in wheat.

CONCLUSION AND RECOMMENDATION

The objective of this study was to evaluate the effect of number of fibrous roots per seedling on plant growth and seed yield of hybrid coffee varieties. Seedlings with at least 18 fibrous roots per seedling increase total seed yield by 146% compared to coffee plants derived from seedlings with 1-9 fibrous roots per seedling, by 110% compared to the control plants and by 83% in comparison to coffee plants derived from seedlings with 10-17 fibrous roots per seedling. It is therefore recommended that farmers should use coffee seedlings with at least 18 fibrous roots per seedling to increase field plant establishment, growth and total seed yield. Further studies are required to determine propagation technologies which can increase the number of roots per seedling to 18 fibrous and 1-4 lateral roots per seedling.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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