

# Planting Density X Mineral Nutrient Interaction Effect on Biomass Production and Partitioning of Arabica Coffee Cultivars

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**To cite this article:**

Wubishet Tamirat. Planting Density X Mineral Nutrient Interaction Effect on Biomass Production and Partitioning of Arabica Coffee Cultivars. *International Journal of Science, Technology and Society*. Vol. 9, No. 5, 2021, pp. 228-233. doi: 10.11648/j.ijsts.20210905.14

**Received:** August 31, 2021; **Accepted:** October 12, 2021; **Published:** October 28, 2021

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**Abstract:** Biomass partitioning is important process for energy distribution among their leaves, stem and roots. The study was designed to evaluate the effect of population densities and fertilizer rates on biomass production and partitioning of Arabica coffee cultivars under nursery conditions. It was conducted at Jimma Agricultural Research Center from (February 29 to October 29), 2018 season. The treatments were arranged by using completely randomized design and a factorial experiment 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 effect of coffee genotypes, population densities and fertilizer rates was highly significant ( $P \leq 0.01$ ) for SFW, TFW and TDW, whereas significant ( $P \leq 0.05$ ) for RFW, LFW, ShFW, RDW, SDW, LDW and ShDW. The result revealed that, the maximum values of fresh weight (RFW, SFW, LFW, ShFW and TFW) and dry weight (RDW, SDW, LDW, ShDW and TDW) were obtained from treatment combinations of 74110\*PD2\*5g of NPK and 75227\*PD1\*5g of NPK in cultivar-74110 and cultivar-75227, respectively. Similarly, maximum biomass partitioning was observed from leaf dry weight as compared stem and root dry weight which were treated with 5g of NPK for both cultivars. Biomass partitioning optimization is very important to minimize the stress imposed by the limiting resource and more attention should be given on a biotic and biotic factor which affects biomass partitioning under field conditions.

**Keywords:** Biomass Partitioning, Coffee Cultivars, Nutrients, Planting Densities

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## 1. Introduction

Biomass partitioning is the process of energy distribution among their leaves, stem, roots and reproductive parts of plant and divided sugar which created by photosynthesis in a way that maximizes growth [1]. Biomass allocation is an important character for the process of characterization of plant physiological ecology. It shows the photosynthates are allocated between above-ground and below-ground biomass [2].

Plants adapt different environmental conditions by distribution of biomass allocation to different parts. It adjusts to variations in resource availabilities by variable partitioning to root and shoot growth [3]. Plants are better able to take resources from their environment and maximize growth by responding to environmental stimuli and partitioning biomass. It partitions biomass in response to limits or excesses in

resources: sunlight, CO<sub>2</sub>, nutrients, and water and its growth is regulated by a constant balance between the partitioning of biomass between plant parts [1]. Phyto-chrome is main light sensing mechanism for plant and it detect of light quality and helps trigger changes biomass partitioning [4]. Leaf is an important source in manufacturing photo assimilates. Plants respond to changing light conditions by adjusting a suite of morpho-physiological traits [5]. According to [6] a 95% plant biomass is derived from carbohydrates manufactured by green parts by the process of photosynthesis and the remaining 5% from mineral elements absorbed by the roots. Pervious results indicated that morpho-physiological and chemical leaf traits vary in response to differences in shade management and nutrients [7].

Dry matter production is depending upon leaf area index, structure of the canopy, photosynthetic rates and strength of

the metabolic sinks [6]. It is varied with accessions, nutrient [8, 9] as well as population density or low light. In addition to this, plant hormone plays a major in biomass partitioning; they affect differentiation and growth of cells and tissues by changing the expression of genes and altering morphology [1]. In general, a biotic factor: sunlight, CO<sub>2</sub>, nutrient and water, and biotic factor: competitions are altered biomass partitioning can be caused by decrease in available resources. The maximum rate of dry matter production within the plant as a whole and partitioning between different parts of the plant has great importance. The study aimed to know the biomass distribution on different plant parts under a biotic and biotic stress conditions. The objective of the study is to evaluate the interaction effect of genotypes, population densities and fertilizer rates on biomass production and partitioning of coffee seedlings under nursery conditions.

## 2. Materials and Methods

### 2.1. Description of Experimental Area

The study was carried out at the Jimma Agricultural

Research Centre (JARC) in Southwestern Ethiopia under nursery for eight months 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 temperatures are 12.77°C and 26.14°C, respectively [5].

### 2.2. 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 (0), 5g and 10g). Compound NPK fertilizer (22: 06: 12 +Te) with 22% total N, 6% P<sub>2</sub>O<sub>5</sub>, 12% K<sub>2</sub>O 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 (Table 1).

Table 1. Total treatment combinations for the study.

Treatments	Main Factors			Treatment Combinations	
	Cultivars	Population Densities	NPK rates (g)		
T1	74110	PD1	0	74110*PD1*0g NPK	
T2			5	74110*PD1*5g NPK	
T3			10	74110*PD1*10g NPK	
T4		PD2	0	74110*PD2*0g NPK	
T5			5	74110*PD2*5g NPK	
T6			10	74110*PD2*10g NPK	
T7		PD3	0	74110*PD3*0g NPK	
T8			5	74110*PD3*5g NPK	
T9			10	74110*PD3*10g NPK	
T10		75227	PD4	0	74110*PD4*0g NPK
T11				5	74110*PD4*5g NPK
T12				10	74110*PD4*10g NPK
T13	PD1		0	75227*PD1*0g NPK	
T14			5	75227*PD1*5g NPK	
T15			10	75227*PD1*10g NPK	
T16	PD2		0	75227*PD2*0g NPK	
T17			5	75227*PD2*5g NPK	
T18			10	75227*PD2*10g NPK	
T19	PD3		0	75227*PD3*0g NPK	
T20			5	75227*PD3*5g NPK	
T21			10	75227*PD3*10g NPK	
T22	PD4	0	75227*PD4*0g NPK		
T23		5	75227*PD4*5g NPK		
T24		10	75227*PD4*10g NPK		

Where, PD1, PD2, PD3 and PD4 are represents population density 1, 2, 3 and 4 seedlings per polythene tube, respectively.

### 2.3. Experimental Procedures

The growth medium was prepared from top soil (0-30 cm depth) from Jimma (Melko) and sand at 3:1 ratio 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 [10]. At the end of experiments seedlings were detached from the soil then washed for root fresh weight, and the samples were separated in to leaf, stem and roots and

oven-dried at 70°C for 24 hours for dry mass, finally fresh and dry biomass data were measured by using sensitive balance [5].

Biomass data: root fresh weight (RFW), stem fresh weight (SFW), leaf fresh weight (LFW), shoot fresh weight (ShFW) = SFW+LFW) and total fresh weight (TFW=RFW+ShFW), root dry weight (RDW), stem dry weight (SDW), leaf dry

weight (LDW), shoot dry weight (ShDW) = SDW+LDW), total dry weight (TDW)= RDW+ShDW) and biomass partitioning were estimated. All relevant data was summarized and subjected to three-way analysis of variance (ANOVA) using SAS 9.0 version [11]. Treatment mean separations were done by least significant difference (LSD) at 5% probability level.

**Table 2.** Effect of coffee cultivars, population densities and fertilizer rates on root fresh weight (RFW), stem fresh weight (SFW), leaf fresh weight (LFW), shoot fresh weight (ShFW) and total fresh weight (TFW) of coffee seedlings.

Treatment Combinations	Fresh Biomass				
	RFW (g)	SFW (g)	LFW (g)	ShFW (g)	TFW (g)
74110*PD1*0g NPK	1.07e-h	0.86efg	1.58g	2.45ghi	3.51gh
74110*PD1*5g NPK	1.6abc	1.3bcd	3.25de	4.55d	6.15cde
74110*PD1*10g NPK	0.15l	0.2ij	0.33i	0.53j	0.68j
74110*PD2*0g NPK	0.69h-k	0.78efg	1.41g	2.19ghi	2.88ghi
74110*PD2*5g NPK	1.99a	2.14a	4.37abc	6.5ab	8.49
74110*PD2*10g NPK	0.44jkl	0.38hij	1.06ghi	1.45ij	1.87ij
74110*PD3*0g NPK	0.98e-h	0.71e-h	1.25gh	1.96ghi	2.95ghi
74110*PD3*5g NPK	1.58bc	1.1cde	2.93de	4.01de	5.59de
74110*PD3*10g NPK	0.15l	0.08j	0.42hi	0.5j	0.65j
74110*PD4*0g NPK	0.69h-k	0.56ghi	1.2gh	1.48hij	2.18hi
74110*PD4*5g NPK	1.24c-f	1.27bcd	2.89de	4.14d	5.38de
74110*PD4*10g NPK	0.15l	0.19ij	0.43hi	0.62j	0.76j
75227*PD1*0g NPK	1.13d-g	1.07bcd	2.53ef	3.8def	4.9ef
75227*PD1*5g NPK	1.89ab	2.03a	5.2a	7.23a	9.1a
75227*PD1*10g NPK	0.13l	0.38hij	1.08ghi	1.45hij	1.58ij
75227*PD2*0g NPK	0.81g-j	0.97def	1.7fg	2.67fgh	3.49gh
75227*PD2*5g NPK	1.47bcd	1.37bc	3.62cd	4.99cd	6.46cd
75227*PD2*10g NPK	0.45i-l	0.54ghi	1.73fg	2.26ghi	2.72ghi
75227*PD3*0g NPK	0.78g-j	1.04c-f	1.8fg	2.84def	3.62fg
75227*PD3*5g NPK	1.32cd	2.02a	4.89ab	6.89ab	8.21ab
75227*PD3*10g NPK	0.44i-l	0.68fgh	1.58g	2.26ghi	2.71ghi
75227*PD4*0g NPK	0.84f-i	0.73e-h	0.94ghi	1.93ghi	2.77ghi
75227*PD4*5g NPK	1.64abc	1.62b	4.18bc	5.8bc	7.44bc
75227*PD4*10g NPK	0.34kl	0.38hij	1.19ghi	1.57hij	1.91ij
LSD (5%)	0.4	0.39	0.87	1.22	1.39
CV (%)	21.05	25.49	24.76	24.16	20.32

Figures followed by same letters within a column for a given variables are not significantly different at 5% probability level.

**Table 3.** Interaction effect of coffee cultivars, population densities and fertilizer rates on root dry weight (RDW), stem dry weight (SDW), leaf dry weight (LDW), shoot dry weight (ShDW) and total dry weight (TDW) of coffee seedlings.

Treatment Combinations	Dry Biomass				
	RDW (g)	SDW (g)	LDW (g)	ShDW (g)	TDW (g)
74110*PD1*0g NPK	0.25d-g	0.27d-g	0.37gh	0.63gh	0.88ghi
74110*PD1*5g NPK	0.37bc	0.37c-f	0.8de	1.17cde	1.53cde
74110*PD1*10g NPK	0.1jkl	0.1h	0.1k	0.2i	0.3kl
74110*PD2*0g NPK	0.19g-j	0.24fg	0.37gh	0.61gh	0.79g-j
74110*PD2*5g NPK	0.393b	0.57ab	1.09bc	1.66ab	2.06b
74110*PD2*10g NPK	0.14ijk	0.19gh	0.28g-k	0.41hi	0.55i-l
74110*PD3*0g NPK	0.26d-g	0.24efg	0.32ghi	0.57gh	0.83g-j
74110*PD3*5g NPK	0.3c-f	0.36c-f	0.74e	1.1def	1.4de
74110*PD3*10g NPK	0.06kl	0.07h	0.12ijk	0.19i	0.25l
74110*PD4*0g NPK	0.18g-j	0.19gh	0.25h-k	0.44hi	0.62ijk
74110*PD4*5g NPK	0.31b-e	0.38cd	0.72e	1.1def	1.41de
74110*PD4*10g NPK	0.05l	0.07h	0.11jk	0.17i	0.23l
75227*PD1*0g NPK	0.23e-h	0.35	0.63ef	0.98ef	1.22ef
75227*PD1*5g NPK	0.52a	0.6ac-f	1.37a	1.97a	2.48a
75227*PD1*10g NPK	0.12jkl	0.13gh	0.27g-k	0.4hi	0.52jkl
75227*PD2*0g NPK	0.24efg	0.34c-f	0.45fg	0.79fg	1.03fg
75227*PD2*5g NPK	0.31b-e	0.38cde	0.95cd	1.33cd	1.64cd
75227*PD2*10g NPK	0.15h-k	0.19gh	0.46fg	0.65gh	0.8g-j
75227*PD3*0g NPK	0.22f-i	0.34c-f	0.47fg	0.8fg	1.02fgh

Treatment Combinations	Dry Biomass				
	RDW (g)	SDW (g)	LDW (g)	ShDW (g)	TDW (g)
75227*PD3*5g NPK	0.33bcd	0.56ab	1.09ab	1.75a	2.08b
75227*PD3*10g NPK	0.087kl	0.18gh	0.41gh	0.59gh	0.68hij
75227*PD4*0g NPK	0.21ghi	0.25d-g	0.31g-j	0.56gh	0.77g-j
75227*PD4*5g NPK	0.36bc	0.45bc	0.99bcd	1.44bc	1.79bc
75227*PD4*10g NPK	0.08kl	0.1h	0.3g-k	0.4hi	0.48jkl
LSD (5%)	0.086	0.136	0.21	0.31	0.354
CV (%)	23.36	29.32	23.38	23.49	20.88

Figures followed by same letters within a column for a given variables are not significantly different at 5% probability level.

**Table 4.** Summary of the ANOVA for root fresh weight (RFW), stem fresh weight (SFW), leaf fresh weight (LFW), shoot fresh weight (ShFW), total fresh weight (TFW), root dry weight (RDW), stem dry weight (SDW), leaf dry weight (LDW), shoot dry weight (ShDW) and total dry weight (TDW) of coffee seedlings.

SV	DF	RFW	SFW	Mean square							
				Fresh Mass				Dry Mass			
				LFW	ShFW	TFW	RDW	SDW	LDW	ShDW	TDW
C	1	0.032 <sup>NS</sup>	1.5**	12.14**	22.23**	23.9**	0.007 <sup>NS</sup>	0.097**	0.8**	1.5**	1.68**
PD	3	0.123*	0.2*	1.08*	2.25*	3.37**	0.015**	0.018 <sup>NS</sup>	0.09**	0.19**	0.28**
F	2	10.27**	935**	581**	113.3**	190.2**	0.41**	0.68**	3.54**	7.22**	11**
C*PD	3	0.126*	0.47**	1.33**	3.34**	3.89**	0.004 <sup>NS</sup>	0.019 <sup>NS</sup>	0.08**	0.17**	0.2*
C*F	2	0.034 <sup>NS</sup>	0.003 <sup>NS</sup>	0.54 <sup>NS</sup>	0.61 <sup>NS</sup>	0.54 <sup>NS</sup>	0.002 <sup>NS</sup>	0.001 <sup>NS</sup>	0.03 <sup>NS</sup>	0.03 <sup>NS</sup>	0.05 <sup>NS</sup>
PD*F	6	0.15**	0.06 <sup>NS</sup>	0.48 <sup>NS</sup>	0.82 <sup>NS</sup>	1.57*	0.007*	0.002 <sup>NS</sup>	0.03 <sup>NS</sup>	0.04 <sup>NS</sup>	0.07 <sup>NS</sup>
C*PD*F	6	0.11*	0.24**	0.68*	1.7*	2.44**	0.007*	0.019*	0.04*	0.12*	0.17**
Error	46	0.037	0.06	0.28	0.56	0.66	0.003	0.007	0.02	0.038	0.05
CV (%)		21.05	25.47	24.8	24.16	20.32	23.36	29.32	23.38	23.49	20.9

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 no significant difference, respectively.

### 3. Results and Discussion

The analysis of variance revealed that the three-way interaction effect of coffee genotypes, population densities and fertilizer rates was highly significant ( $P \leq 0.01$ ) for SFW, TFW and TDW, whereas significant ( $P \leq 0.05$ ) for RFW, LFW, ShFW, RDW, SDW, LDW and ShDW (Table 4).

The result revealed that, the maximum values of 1.99, 2.14, 4.37, 6.51 and 8.49g of RFW, SFW, LFW, ShFW and TFW, whereas highest values of 0.39, 0.57, 1.09, 1.66 and 2.06g of RDW, SDW, LDW, ShDW and TDW, respectively were obtained from treatment combinations of 74110\*PD2\*5g of NPK in cultivar-74110. Similarly, highest values of 1.87, 2.03, 5.2, 7.24 and 9.1g of RFW, SFW, LFW, ShFW and TFW, whereas maximum values of 0.52, 0.6, 1.37, 1.97 and 2.48g of RDW, SDW, LDW, ShDW and TDW, respectively were obtained from treatment combinations of 75227\*PD1\*5g of NPK in cultivar-75227 (Tables 2 and 3).

Dry weight reflects the functional aspects of all assimilation. Environmental factors affect dry matter biomass partitioning between roots and shoots. The allocation of dry matter among roots and shoots in seedlings developed different it might be related with different population density. Similar reports indicate that variation in morphology and proportions of distribution and allocation of dry matter in the structures [12]. Photosynthetic and nitrogen assimilates are allocated to various parts of the plant in ratios are due to regulatory mechanisms [6]. Cultivar-75227 was highest fresh and dry biomass as compared with cultivar-74110 (Figure 1a)

it might be due variations in morphological growth. Highest root and shoot dry matter were obtained from population densities 1 and 2, respectively (Figure 1b). According to [4] plants grown under low light conditions more biomass is allocated to shoots (mainly leaves), but decreases the energy partitioned to the roots because the lower rates of photosynthesis lessen need for water and mineral nutrients. Maximum values for RDW, ShDW and TDW were obtained from 5g of NPK in all treatment combinations (Figure 1c), with 106.8, 172.13 and 160.76% in cultivar-74110, whereas with 126.08, 101.02 and 96.7% increments over the control for cultivar- 75227, respectively.

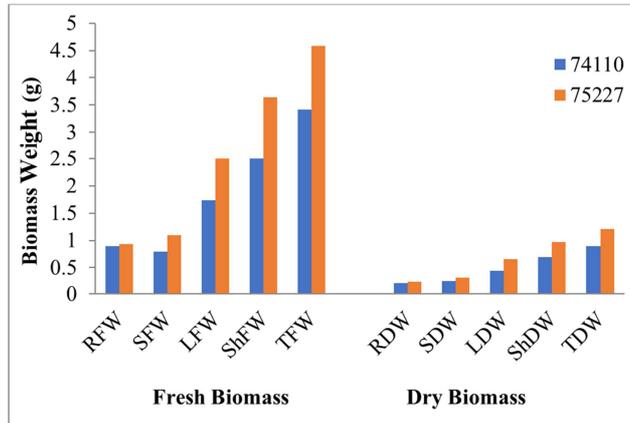
The dry matter partitioning for RDW, SDW, LDW and ShDW which were treated with 5g of NPK as derived from Table 3 showed that, biomass partitioning for RDW (19.08-24.88% and 15.85-20.95%), SDW (23.61-27.29% and 23.98-26.94%), LDW (50.74-53.96% and 54.96-57.9%) and ShDW (75.12-80.92% and 79.06-84.14%) were obtained from cultivar-74110 and 75227, respectively. Highest biomass partitioning was observed for LDW as compared with RDW and SDW it might be high leaf weight ratio. Similar finding reported that leaf weight ratio is a determinant of relative growth rate of trees in early stages and also it is determining allocation of biomass to the leaves and other parts. However, higher leaf weight ratio means faster expansion of leaf area and light capture [13]. The leaf areas of coffee plant are indirectly affected by translocation of dry matter to organ parts (root, trunk, leaves and branches) [14].

In addition to this biomass partitioning was increased on ShDW as compared with RDW. Nutrient availability has a

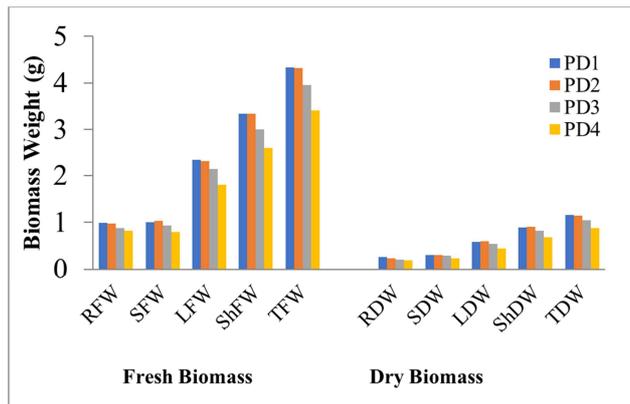
strong effect on biomass partitioning; fraction of biomass partitioned to shoot increased with increasing both shading and N supply [15].

Similar findings reported that, as soil fertility increases, biomass is primarily allocated to above ground structures such as leaves and stems [9]. The changes in root: shoot ratio is accompanied by change in nutrient, water availability and carbon metabolism, which affects dry matter partitioning [16].

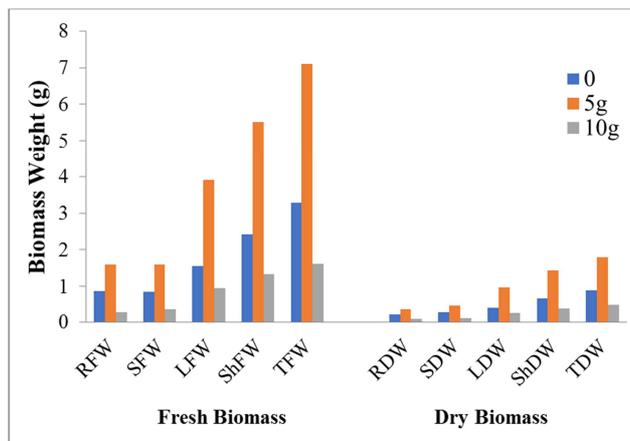
Application of 10g of NPK adversely affected both fresh and dry mass of coffee seedlings. In line with this result, high concentrations of a mineral nutrient that lead to toxicity can have a strong effect on growth and partitioning [17]. This result was in agreement with the findings of [18] who reported that, doses above optimum N amount from 0.8 or 1.2g plant<sup>-1</sup> gave rise to N luxury consumption causing adverse effects on coffee seedling growth.



a)



b)



c)

Figure 1. Effect of main factors (a) coffee cultivars, (b) population densities and (c) fertilizer rates on RFW, SFW, LFW, ShFW, TFW, RDW, SDW, LDW, ShDW and TDW. Where, PD1, PD2, PD3 and PD4 are represents population density 1, 2, 3 and 4 seedlings per polythene tube, respectively.

## 4. Conclusion

It was observed that highest root and shoot for both fresh and dry weight were obtained from treatment combinations of 74110\*PD2\*5g of NPK and 75227\*PD1\*5g of NPK in cultivar-74110 and 75227, respectively and similar results were obtained for total fresh and dry mass from the same treatment combinations. In addition to this, maximum biomass partitioning was obtained from leaf as compared with stem and root dry mass. In general, treatment combinations of 74110\*PD2\*5g of NPK and 75227\*PD1\*5g of NPK in cultivar-74110 and 75227, respectively is best treatment combinations for root, shoot and total dry mass.

## 5. Recommendation

Biomass partitioning optimization is very important to minimize the stress imposed by the limiting resource. Therefore, optimization of population density as well as more attention should be given on a biotic and biotic factor which affects biomass partitioning under field conditions.

## Acknowledgements

I would like to thanks Ethiopian Institute of Agricultural Research (EIAR) for financial support.

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