Effect of Integrated Application of Mineral Fertilizer and Green Manure on Soil Chemical Properties, Coffee Yield and Bean Quality, and Weed Control in Jimma, Southwest Ethiopia

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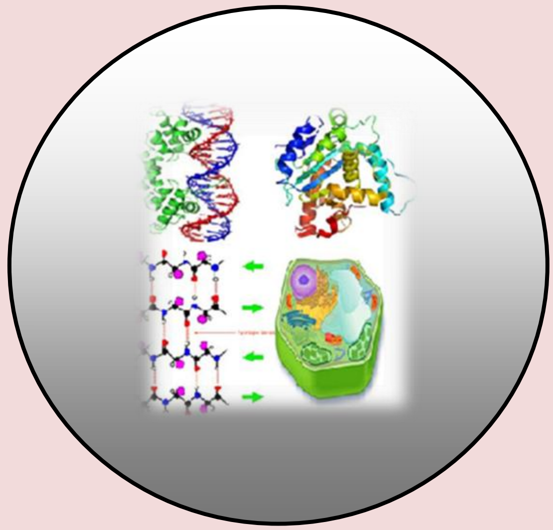

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RESEARCH PAPER

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Effect of Integrated Application of Mineral Fertilizer and Green Manure on Soil Chemical Properties, Coffee Yield and Bean Quality, and Weed Control in Jimma, Southwest Ethiopia

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ABSTRACT

Field experiment was conducted on newly planted compact coffee variety 74110 at Jimma Agricultural Research Center (JARC), southwest Ethiopia, from 2014/16 to 2019/20 cropping calendar to assess the combined effect of mineral fertilizer rates and green manure (Desmodium spp.) on soil chemical properties, Arabica coffee yield and bean quality, and weed growth and control efficiency. The treatments consisted control (plot receiving neither mineral fertilizer nor Desmodium), recommended rate of mineral fertilizer (RMF) (172 and 63 kg ha^{-}1 N and P, respectively), Desmodium alone (without mineral fertilizer), 25 % RMF + Desmodium, 50 % RMF + Desmodium and 75 % + Desmodium. The experiment was laid out in a RCBD with three replications. Laboratory analysis results of composite soil samples collected from experimental field before commencement of the trial showed the soil is very acidic with pH of 4.90 and has low exchangeable Ca and Mg, organic C, total N and available P. However, soil samples collected from each experimental plot at the completion of the study indicated significant ($P \leq 0.05$) effect and improvement on soil chemical properties such as, organic C, total N and available P. Furthermore, the analysis of variance of each cropping year and combined analysis of year by treatments interaction revealed that the treatments significantly ($P \leq 0.05$ or 0.01) affected coffee yield and bean quality, weed biomass and control efficiency. The highest but statically at par clean coffee yields of 1186.9 and 1276.1 kg ha^{-1}, and net benefits of 63067.60 and 61943.90 Ethiopian Birr (EtB) was obtained from the application of 50 % RMF + Desmodium and RMF, respectively.

Similarly, application of mineral fertilizer + Desmodium significantly improved the quality of coffee beans, as measured by row characters and liquor tastes, when compared to coffee bean from control treatments. Likewise, the lowest weed biomass and highest weed control efficiency of 244.4 kg ha^{-1} and 88.72 %, 50 %, respectively, resulted from application of RMF + Desmodium treatments. Therefore, it can be concluded that combined application of 50 % RMF and Desmodium was an alternative management option to mineral fertilizer in enhancing soil fertility, Arabica coffee yield and bean quality in Jimma and surrounding areas. However, more research is required at different coffee growing agro-ecologies of the country to develop an economically viable combination of mineral fertilizer rates, Desmodium and lime for sustainable long-term soil productivity improvement, reduce mineral fertilizer consumption and less environmental pollution due to nutrient losses in to the soil and improved Arabica coffee production, productivity and quality in the country.
Keywords: Arabica coffee, clean coffee yield, Desmodium, economic return, Green manure and Mineral fertilizer.

INTRODUCTION

Land degradation is one of the most challenging problems in Ethiopia's coffee growing areas, limiting the productivity and quality of the country's coffee industry (Solomon, 2014; Yilma, 2017; Anteneh and Bikila, 2021). As a result, Paulos (1994) recommends mineral fertilizers for the crop grown in the country's major coffee producing agro-ecologies. However, given the country's current low and variable coffee bean prices, as well as the escalating price of chemical fertilizers, resource-poor and subsistence coffee farmers either not apply or apply suboptimal level of the recommended rates of mineral fertilizers to their coffee orchards (Anteneh and Bikila, 2021). These factors limit the spread and adoption of improved coffee varieties that produce high yields when mineral fertilizers are applied at the recommended rate and time. As a result, there is an urgent need to investigate low-cost and easily accessible alternative nutrient sources that could be integrated with mineral fertilizers to increase/maintain soil productivity, growth, yield, and quality of coffee in the country.

Because soil productivity cannot be improved solely through the application of inorganic or organic fertilizers, the integration of inorganic fertilizers with green manure crop is a valuable and sustainable alternative resource for long-term soil productivity improvement and reduces environmental pollution due to nutrient losses in to the soil (Bora et al., 2008; Yilma, 2017; Anteneh and Bikila, 2021). The incorporation of inorganic fertilizer with green manure crops can significantly improve degraded soil by increasing plant nutrient supply in the soil, improving soil porosity and air capacity, and increasing moisture content in the 0-30 cm soil layer, improve crop nutrient use efficiency, provide good ground cover for reducing soil erosion caused by raindrop impact and runoff, smother weed growth, and serve as a source of food and fodder for dairy production (Taye *et al*., 2008; Diriba *et al*., 2020). Furthermore, in today's market, where coffee buyers are enthusiastic about organic coffee, coffee grown with organic sources of nutrients commands a premium price in the global market while maintaining ecologically sound and economically viable farming systems (Van Der Vossen, 2004; Taye *et al*., 2008).

Furthermore, the use of green manure to supplement inorganic fertilizer has been adopted to reduce the use of chemical fertilizer in agriculture, and it is critical to produce more crop yield with less environmental impact, such as lower nutrient losses (Xie *et al*., 2016).

Given the practical importance of green manure crops, a study was conducted in unreplicated observational plots at JARC to evaluate the adaptation and soil improving characteristics of a number of green manure cover crops *viz.*, *Tithonia diversifolia, Mucuna pruriens, Desmodium* spp*., Crotolaria paulina, Tephrosia candida, and Leucaena leucocephala*. The results were revealed that, among the studied green manure crops, *Desmodium* spp. and *Crotolaria paulina* are the best legumes, with good performance and adaptation, as well as improved soil N, P, and organic carbon content (Taye *et al*., 2008; Anteneh *et al*., 2015; Anteneh and Bikila, 2021).

Desmodium is a shade-loving (C_3) leguminous green manure cover crop that produces abundant and easily degradable biomass that improves soil moisture, organic carbon and, nutrients and prevent soil erosion, smother weed growth and serve as animal feed (Kimemia *et al*., 2001; Mureithi *et al*., 2003; Anteneh *et al*., 2015; Anteneh Bikila, 2021). Experiments at Jimma revealed that planting *Desmodium* spp. as a cover crop between coffee tree rows conserved soil moisture and increased coffee yield by 30% when compared to coffee plot without *Desmodium* (Taye *et al.*, 2008). However, most of these advantages of *Desmodium* have not yet to be implemented in Ethiopian coffee farming systems to ensure the crop's long-term viability. As a result, information on the complementary effect of this leguminous green manure cover crop and mineral fertilizers on soil fertility/productivity and coffee yield and quality in the country is limited. The current study was, therefore, conducted with the objectives to investigating the effect of integrated application of mineral fertilizer and *Desmodium* on soil chemical properties, Arabica coffee yield and bean quality, weed growth, and economic benefit in Jimma, southwest Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

The research was carried out at Jimma Agricultural Research Center, southwest Ethiopia, from 2015/16 to 2019/20 crop seasons. The center is situated in sub-humid tepid to cool mid high lands agro-ecological zone. It is located at 7^0 46' N latitude 36^0 47' E longitudes (Fig. 1a) at an elevation of 1753 m above sea level. It receives mean annual rainfall of 1521 mm, with unimodal pattern, the peak being in July. Usually the rainfall starts in March and may extend up to September or November. The area's has mean annual minimum and maximum temperatures of 12.1 and 26.2 ^{0}C, respectively (Fig. 1b). The study area has *Nitisols* in the upper slopes and *Planosols* in the low lying plain areas (De Wispelaere *et al.,* 2015). On the average, the soil is deep and relatively highly weathered well drained, clay in texture and strongly to moderately acidic in reaction (Paulos, 1994).

Experimental Design and Treatment Set up

The experiment was conducted on newly planted compact coffee variety 74110. The seedling of the variety was planted to field in July 2014/15 at a spacing of 2 m *2 m. Each experimental unit was consisted of 30 coffee trees. In the experimental field, temporary shade tree, such as *Sesbania sesbane,* was planted at the spacing of 4 m *4 m in between rows of coffee trees at the time of planting coffee seedlings in the experimental field.

Coffee yield data of four consecutive years, 2016/17-2019/20 were collected from the experiment.

The trial consisted six treatments *viz.*, control (without mineral fertilizers *and Desmodium*, negative control), *Desmodium* only (without mineral fertilizer), recommended rate of mineral fertilizer (RMF) (172 and 63 kg ha^{-1} N and P, respectively), 25 % RMF + *Desmodium*, 50 % RMF + *Desmodium* and 75 % RMF + *Desmodium*. The experiment was conducted in a RCBD with three replications.

(a) (b)

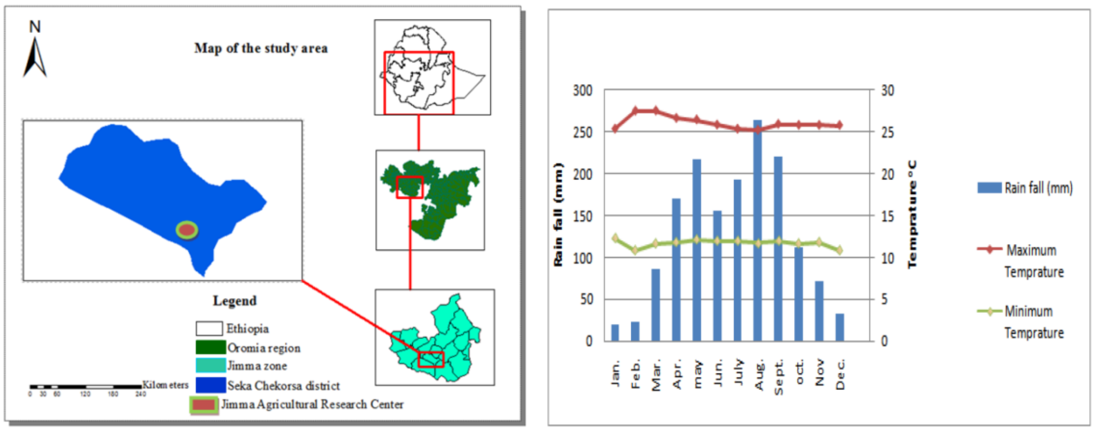


Figure 1. Location map (a) and mean monthly minimum and maximum temperature (^{0}C) and mean monthly total rain fall (mm) (b) of the study area (2012-2020). Source*:* Regional statistic and population office of SNNPR; JARC Agro metrology (2020).

In *Desmodium*-treated plots, crop seeds were hand drilled in rows in April 2015 at a seed rate of 5 kg ha^{-1} by mixing with 20 kg ha^{-1} of sand in the inter- and intra-raw space between the coffee trees 60 cm away from the main stems of the trees. The crop was then allowed to grow freely before being slashed, chopped, and mulched around the respective experimental coffee trees in a plot each year during the study period at flowering in September.

Urea (46 % N) and TSP (46 % P_2O_5), respectively, were used as a source of N and P, to reduce urea loss and increase its efficiency, it was applied in three equal splits: March/April, June/July, and September, while P was applied in two equal splits (half in March/April and the other half in September). Fertilizer was applied in a band around the coffee trees at a depth of 20 cm and then covered with soil. Except for the experimental variables, all recommended agronomic management practices were applied uniformly to all experimental plots until the completion of the experiment (Anteneh *et al*., 2015).

Data Collected

Soil Sampling and Analysis

Before treatment application, soil samples were collected from experimental field from 20 random auguring points at 0-30 cm depth and then bulked into one composite sample.

Similarly, after harvest of 2019/20 cropping season, soil samples were collected from the same depth from each experimental unit and replication of the trial separately and composited by replication to obtain one representative sample per treatment. The collected soil samples were air dried, ground, and sieved with a 2 mm sieve before being analyzed at the JARC Soil, Water and Plant Tissue Analysis Laboratory.

Texture was determined by the hydrometer method (Day, 1965). Soil pH was measured in a 1:2.5 (soil: water) ratio using a glass electrode pH meter (Peech, 1986). McLean's method was used for determining exchangeable acidity (VanReeuwijk, 1992). Exchangeable Ca, Mg, K, Na and cation exchange capacity was determined following the method employed by Champan (1965). Organic carbon was determined by the modified Walkley and Black procedure as described by Nelson and Sommers (1982). Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described by van Reeuwijk (1992). Avilable forms of P were extracted with a HC1: NH4F mixture (Bray's No. II method) as described by Olsen and Sommers (1982).

Coffee Yield and Bean Quality

Coffee yield was collected from each experimental plot and replication separately from 2016/17 - 2019/20 cropping seasons. Furthermore, At the completion of the study, 2019/20 main harvesting season, red ripe cherries were handpicked from each experimental unit and replication and was prepared by wet processing method to standard moisture content of 11-12% (Behailu *et al*, 2008). Then after, the parchment was removed by huller and the beans were handed over to JARC Coffee Processing and Quality Analysis Laboratory for row quality (bean shape, make, color and odor) and cup quality (acidity, body, flavor, aroma, fragrance, and aftertaste) and overall quality analysis. Row quality was evaluated using the standard procedures and cup quality will be evaluated by panel of 3-4 trained, experienced and internationally certified cuppers (Q graders) and were accounted 40 and 60% total coffee quality as shown in Table 1.

Table 1. Standard parameters and their respective values used for row, cup, total row and cup and overall coffee bean quality evaluation.

Parameters	Row and total row values	Cup and total cup values	Overall quality	
			Parameters	values
Fair	<20	<30	Fair and reject	<50
Average	20-26	30-35	Average and acceptable	50-65
Good	27-34	36-44	Good and acceptable	66-80
Very good	35-40	45-60	Very good and highly acceptable	81-100

Source: Abrar and Negussie (2015).

Weed Biomass and Control Efficiency

At the end of the experiment (2019/20 cropping season), weed biomass was collected using a 1 m * 1 m measuring quadrant placed on each experimental plot.

The weed inside the quadrant was then slashed and placed into labeled paper bags and dried in an oven at 65 ^{0}C. Finally, the weed's dry weight in the paper bag was measured and converted to kg ha^{-1}. Furthermore, weed control efficiency was calculated using the weed dry matter weight per treatment using the formula used by Patel *et al*. (2006) as follows:

$$WCE\ (\%) = \frac{WDMC - WDMT}{WDMC} \times 100$$

Where, WCE = Weed control efficiency, WDMC = Weed dry matter in a control plot, and WDMT = Weed dry matter in a treatment plot.

Data Analysis

SAS statistical software was used to analyze the collected soil chemical analysis, coffee yield and bean quality, weed biomass, and weed control efficiency data (SAS Institute Inc., version 9.1, 2008). Duncan's Multiple Range Test at 5% probability level was used to compare and separate significant differences between treatment means whenever the treatment differences were significant (Mandefero, 2005).

Partial Budget Analysis

Partial budget analysis described by CIMMYT (1988) was used to assess the profitability of the treatments used in this trial. For these cost of fertilizers, coffee bean yield and market price of coffee bean was considered. The purchasing price of mineral fertilizers of farmers' cooperatives in the region was used to calculate the total cost of applied mineral fertilizer. Coffee bean prices [Ethiopian Birr (EtB) kg^{-1} of bean] for the study site was obtained from ESEX office of Jimma town. Accordingly, coffee bean, TSP and urea were valued at average open market price of 65.00, 13.50 and 12.68 Birr kg^{-1}, respectively. The wage rate per person per 8 hour was 30 Birr for fertilizer application. Accordingly, it was 555.5 Birr ha^{-1} for both TSP and urea per split application. In addition, data were collected for the following parameters: Gross average coffee bean yield (kg ha^{-1}) (GACY): an average yield of each treatment converted in hectare base. Adjusted coffee bean yield (ACY): Average yield adjusted downward by 10% to minimize plot management effect by the research or to reflect the actual farm level performance as described by Akinpelu *et al*. (2011). Thus: ACY (kg ha^{-1}) = GACY × (1 - 0.1). Gross field benefit (GFB) (Birr ha^{-1}) was computed by multiplying field/farm gate price (kg ha^{-1}) by adjusted yield thus: GFB = ACY× field/farm gate price for the crop. Total variable cost (TVC): cost of labor, labor used to apply fertilizer used for the experiment. The costs of other inputs and production practices such as labor cost for land preparation, planting, weeding, crop protection and harvesting was considered to remain the same or will be insignificant among treatments. Net benefit (NB) (Birr ha^{-1}): for each treatment is the difference between the gross field benefit and the total variable costs thus: NB = GFB – TVC.

The marginal rate of return (MRR %) is calculated by dividing the change in net benefit by the change in variable cost (CIMMYT, 1988), as follows:

$$MRR\ (\%) = \frac{Change\ \ in\ benefit\ \ (NB1 - NB2)}{Chnge\ \ in\ TVC\ \ (TVC1 - TVC2)} * 100$$

Where, NB1 denotes the net benefit of treatment 1, NB2 denotes the net benefit of treatment 2, TVC1 denotes the total/variable cost of treatment 1 and TVC2 denotes the total/variable cost of treatment 2.

RESULTS AND DISCUSSION

Selected soil physico-chemical properties of experimental site before commencement of the experiment

Result of laboratory analysis of selected physicochemical properties of soil of experimental site before commencement of the experiment was presented in Table 2. The result showed that the soil has sandy-clay loam texture (46.5, 19.0 and 31.5% sand, clay and loam, respectively) and a pH of 4.90. According to London (1991), the soil of experimental site had very strong acidity and high exchangeable acidity, and had low levels of basic cations such as K^+ (1.80 $cmol_c$ kg^{-1} soil), Ca^{2+} (5.44 $cmol_c$ kg^{-1} soil) and Mg^{2+} (1.89 $cmol_c$ kg^{-1} soil). Besides, organic C and total N were also found to be below average that is 0.73 and 0.14%, respectively (Table 2). The Bray-II extractable available P was 3.50 mg kg^{-1}, which was significantly lower than the threshold amount for coffee plant growth and yield reported by Abayneh and Fisseha (2015). This limits coffee growth and yield by increasing the solubility and availability of Al^{3+} while decreasing the availability of P through increased P fixation as insoluble Al phosphates (Achalu, 2014; Anteneh, 2015). This has a direct impact on coffee growth, yield and quality by inhibiting root formation and lowering macronutrient availability to plants, particularly P, which is readily available in the medium pH range (Anteneh, 2015; Brady and Weil, 2017). The findings explicitly justify the need for soil amelioration and external application of nutrients based on the rate recommended for crops grown in the area.

Table 2. Selected soil physico-chemical properties of experimental site before start of the experiment.

Soil Properties	Values	Rate*
Soil texture		
Sand (%)	46.5	
Silt (%)	19.0	
Clay (%)	31.5	
Textural class	Sandy clay loam	
Soil chemical property		
pH	4.90	Very strong acidic
Exchangeable acidity ($cmol_c$ kg^{-1})	2.55	Low
Exchangeable Ca ($cmol_c$ kg^{-1} soil)	5.44	Low
Exchangeable Mg ($cmol_c$ Kg^{-1} soil)	1.89	Low
Exchangeable K ($cmol_c$ kg^{-1} soil)	1.88	Very high
Exchangeable Na ($cmol_c$ kg^{-1} soil)	0.06	Enough
Organic C (%)	0.73	Low
Total N (%)	0.14	Low
Available P (mg kg^{-1})	3.50	Low

* = Abayneh and Fisseha (2015)

Effect of integrated application of mineral fertilizer and green manure on
Soil chemical properties at the completion of the study

Post-harvest soil pH, organic C, total N and available P are presented in Table 3. Results of analysis of variance indicate that there were significant ($P \leq 0.05$) differences in soil pH among the different treatments. Accordingly, the control and *Desmodium*-only treated plots had significantly ($P \leq 0.05$) higher pH levels (5.00 and 5.09, respectively), while plots treated with RMF and mineral fertilizer + *Desmodium* had lower pH level (Table 3) indicated that the status of soil pH was not improved in the study by applied treatments. The acidifying effect of N mineral fertilizers could be attributed to the low soil pH in RMF and integrated application of mineral fertilized and *Desmodium* treated plots reported in this study (Brady and Weil, 2017). The absence of pH improvement by treatments in this study indicates that additions of lime to the experimental sites were required to ameliorate and increase soil pH, and increase soil nutrients for plants uptake (Kebede and Dereje, 2017).

Table 3. Effects of integrated application of mineral fertilizer and *Desmodium* on chemical characteristics of soils of the experimental site at the completion of the study.

Treatment	pH (H_2O)	OC (%)	TN (%)	AvP (mg kg^{-1})
Control	5.00^{a}	1.60^{b}	0.15^{c}	2.78^{c}
D	5.09^{a}	1.82^{b}	0.17^{b}	5.47^{b}
RMF	$4.86b^{c}$	1.80^{b}	0.17^{b}	5.28^{b}
25% RMF + D	4.96^{b}	1.81^{b}	0.17^{b}	5.22^{b}
50% RMF + D	4.90^{b}	2.06^{a}	0.20^{a}	6.51^{a}
75% RMF + D	4.84^{c}	1.84^{b}	0.18^{b}	6.40^{a}
F-test	*	*	*	*
SE($\pm$)	**0.01**	**0.07**	**0.01**	**0.22**
CV(%)	**1.32**	**21.71**	**18.70**	**11.90**

* = Significant at 0.05 probability level. Means followed by same letter(s) within a column are not significantly different at $P \leq 0.05$. RMF = Recommended mineral fertilizer (172 and 63 kg ha^{-1} N and P, respectively), D = *Desmodium,* OC = Organic carbon, TN = Total N, and AvP = Available P.

The results also indicated that there were significant ($P \leq 0.05$) differences in soil organic C, total N and available P among treatments. Higher concentrations of soil organic C, total N, and available P resulted from the application of 50 % RMF + *Desmodium* and 75 % RMF + *Desmodium*. In contrast, lower concentration of soil organic C, total N, and available P were registered in the control plot (plot treated with neither inorganic fertilizers nor *Desmodium*) (Table 3). The result genially confirmed that the status of soil organic C, total N and available P after crop harvest was greatly enhanced as compared to their initial soil concentration before commencement of the trial (Table 2 and 3), indicated that microorganism decomposing green manure residues enhance the concentration of the nutrients in the soil in mineral fertilizer + *Desmodium* treated plots.

The current findings are consistent with the report of Saintz *et al*. (1998) and Roberts (2010) who are reported that the residual effects of green manure applications significantly increased soil organic C, nitrates, phosphates, exchangeable Ca and some other nutrients for plants. Bora *et al*. (2008) and Melak and Kopainsky (2014) also reported the use of organic fertilizers from green manure may have made the soil porous and pulverized due to increased soil organic C, which allows for better root growth and development. Similarly, Brady and Weil (2017) reported that interactions between chemical fertilizer and green manure can improve soil fertility by replenishing nutrients lost through leaching and modifying the pH of the rhizosphere and making nutrients accessible to the plant root. In general the result confirmed that the available nutrient status of soil was greatly enhanced by integrated application of mineral fertilizer and green manure.

Coffee yield

Table 4 presents the means of clean coffee yield as influenced by integrated application f mineral fertilizer rate and *Desmodium*. The result of analysis of variance indicated significant ($P \leq 0.05$), highly significant ($P \leq 0.01$) and non-significant ($P > 0.05$) clean coffee yield variation in 2016/17 and 2017/18, 2019/20, and 2018/19 cropping seasons, respectively due to application of mineral fertilizer and *Desmodium.* Likewise, the combined analysis of variance over four years also revealed that integrated application of mineral fertilizer and *Desmodium* had a highly significant effect on mean clean coffee yield (Table 4).

In the first and second crop seasons, higher mean clean coffee yields of 1339.7 and 1134.3 kg ha^{-1} were harvested from plots treated with RMF and 50 % RMF + *Desmodium*, respectively. Although yield variation was non-significant in the subsequent third crop season, a relatively better clean coffee yield of 1204.5 kg ha^{-1} followed by 1079.2 kg ha^{-1} was recorded from the respective plots treated with 50 % RMF + *Desmodium* and 25 % RMF + *Desmodium* (Table 4).

However, in the fourth year the highest and non-significant clean yield of 1574.0 kg ha^{-1} followed by 1231.9 and 1122.7 kg ha^{-1} was obtained from plots treated with 75 % RMF + *Desmodium*, 25 % RMF + *Desmodium*, and RMF, respectively. In contrast, the control (plot treated with neither mineral fertilizer nor *Desmodium*) and *Desmodium* (without mineral fertilizer) treated plots had significantly lower mean clean coffee yields across all crop seasons (Table 4). The low yield recorded from plots treated with control and *Desmodium* only treated plots could be attributed to weeds and *Desmodium* cover crop competition for available soil nutrient and moisture in the respective plots with coffee trees. In general, the results indicated that inconsistent coffee yield variations across crop seasons. This could be attributed to the biennial bearing nature of the crop (Wintgens, 2004; Yilma, 2017).

Result of combined year analysis showed that integerated application of mineral fertilizer and green manure has significant ($P \leq 0.01$) effect on clean coffee yield (Table 4). Plots receiving RMF, 50 % RMF + *Desmodium*, 75 % RMF + *Desmodium*, and 25 % RMF + *Desmodium* gave the highest but statistically at par clean coffee yields of 1276.1, 1186.9, 1090.7, and 1031.8 kg ha^{-1}, respectively, with percent yield increments of 113.1, 98.28, 82.21, and 72.34 % over the control plot. On the other hand, lowest clean coffee yields of 826.6 and 598.6 kg ha^{-1}, respectively was obtained from the control and *Desmodium* only treated plots (Table 4).

The highest yield obtained from the integrated application of mineral fertilizer and green manure could be attributed to the decomposition of organic residues from green manure promotes better root growth, nutrient absorption and improves nutrient status of soil, both macro-nutrients and micro-nutrients. The high competition of weeds and *Desmodium* grown in the respective experimental plot with coffee trees for available soil nutrients and moisture may have contributed to the low coffee yield observed in the control and *Desmodium* alone treated plots. In conclusion leguminous green manure crops are the recently organic fertilizer in supplementing chemical fertilizers for sustainable increase and development in the productivity capacity of degraded soil and increasing Arabica coffee yield.

Table 4. Effects of integrated application of mineral fertilizer and *Desmodium* on clean coffee yield (kg ha^{-1}).

Treatment	Clean coffee yield (kg ha^{-1})				Over years mean clean coffee yield (kg ha^{-1})	% yield increase over the control
	2016/17	2017/18	2018/19	2019/20		
Control	520.3^{c}	929.4^{b}	590.4	354.3^{d}	598.6^{b}	-
D	673.0b^{c}	960.2^{b}	892.7	780.7^{c}	826.6^{b}	38.01
RMF	1339.7^{a}	1614.2^{a}	918.5	1231.9^{ab}	1276.1^{a}	113.18
25% RMF + D	896.7b^{ac}	1028.5^{b}	1079.2	1122.7^{bc}	1031.8^{a}	72.34
50% RMF + D	1134.3ab	1495.3^{a}	1204.5	913.4^{bc}	1186.9^{a}	98.28
75% RMF + D	749.0b^{c}	1269.4b^{a}	770.4	1574.0^{a}	1090.7^{a}	82.21
F-test	*	*	**NS**	**	**	
SE($\pm$)	**54.09**	**45.42**	**72.48**	**78.02**	**32.47**	
CV(%)	**33.7**	**20.6**	**44.1**	**20.20**	**16.87**	

NS, * and ** = Non significant and significant at 0.05 and 0.01 probability level, respectively. Means within a column followed by same supper script letter(s) are not significantly different at 0.05 probability level. RMF = Recommended mineral fertilizer (172 and 63 kg ha^{-1} N and P, respectively) and D = *Desmodium*.

Coffee Bean Quality

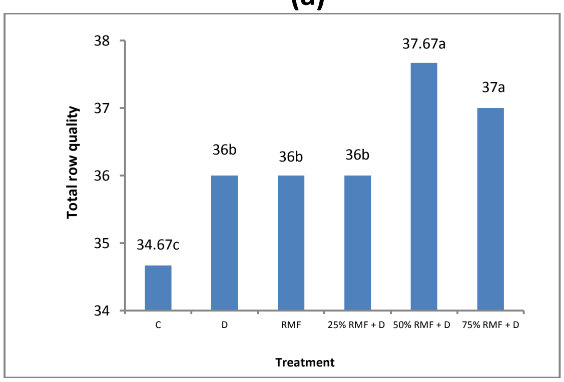
Shape and make, and color of coffee bean were significantly ($P \leq 0.05$) affected by mineral fertilizer and *Desmodium* treatments, with the highest and lowest mean values of 13.17 and 12.00 for shape and make, and 14.67 and 12.67 for color resulted from 50 % RMF + *Desmodium* and control treatments. On the other hand, there were insignificant ($P > 0.05$) differences between treatments mean for the rest of the shape and make, color, and odor values (Table 5). Similarly, liquor quality of coffee bean, as measured by acidity, body, and flavor in the cup taste, was significantly ($P \leq 0.05$) improved by mineral fertilizer + *Desmodium* treatments when compared to coffee bean from control and *Desmodium* alone treated plot.

Table 5. Effect of integrated application of mineral fertilizer and *Desmodium* on raw and cup quality of coffee beans.

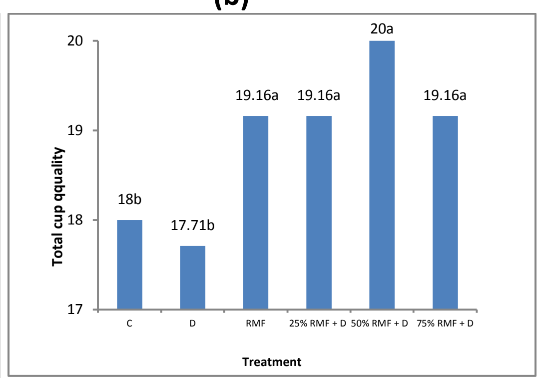
Treatment	Row quality (40%)			Liquor quality (60%)		
	Shape and make	Color	Odor	acidity	Body	Flavor
Control	12.00^{c}	12.67^{c}	10.00	4.17^{c}	7.00^{c}	6.83^{b}
D	13.00^{b}	13.00^{b}	10.00	4.17^{c}	6.83^{c}	6.71^{b}
RMF	13.00^{b}	13.00^{b}	10.00	4.33^{b}	7.50^{b}	7.33^{a}
25% RMF + D	13.00^{b}	13.00^{b}	10.00	4.33^{b}	7.50^{b}	7.33^{a}
50% RMF + D	13.17^{a}	14.67^{a}	10.00	4.50^{a}	8.00^{a}	7.50^{a}
75% RMF + D	13.00^{b}	14.00^{a}	10.00	4.33^{b}	7.50^{b}	7.33^{a}
F test	*	*	**NS**	*	*	*
CV (%)	**0.9**	**1.69**	**-**	**14.70**	**5.75**	**4.01**

NS and * * = Non significant and significant at 0.05 probability level, respectively. Means within a column followed by same supper script letter(s) are not significantly different at 0.05 probability level. RMF = Recommended mineral fertilizer (172 and 63 kg ha^{-1} N and P, respectively) and D = *Desmodium*.

(a)



(b)



(c)

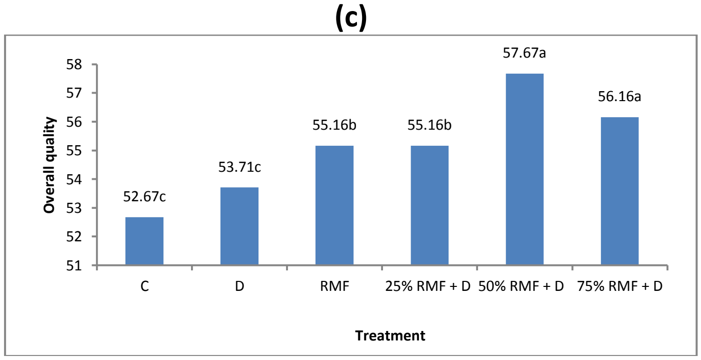


Figure 2. Impact of a combined application of mineral fertilizer and *Desmodium* on raw total (a), cup total (b), and overall coffee bean quality (c). Bars capped with the same letter are not significantly different at *P* = 0.01 probability level. C = Control, D = *Desmodium* and RMF = Recommended rate of mineral fertilizer (172 and 63 kg ha^{-1} N and P, respectively).

Accordingly, the highest and lowest mean values of liquor quality were recorded from plots treated with 50 % RMF + *Desmodium* and *Desmodium* only plot (Table 5); indicating that the intenerated use of *Desmodium* and mineral fertilizer in coffee farms improve the cup quality of coffee beans.

Total row and total cup quality were significantly ($P\leq0.05$) affected by integrated application of mineral fertilizer and *Desmodium* treatments, with the highest values of 37.67, and 20 recorded for plots treated with 50 % RMF + *Desmodium*. The lowest values, on the other hand, were found in the control and *Desmodium* only treated plots (Figure 2a and b). However, the treatments had a significant ($P\leq0.05$) effect on overall coffee quality, which followed the order 50 % RMF + *Desmodium* > 75 % RMF + *Desmodium* > RMF = 25 % RMF + *Desmodium* > *Desmodium* > control (Figure 2c). Significantly, the control and *Desmodium* only treated plots had the lowest overall coffee bean quality (Figure 2c). In general, the results showed that integrated application of mineral fertilizer and *Desmodium* significantly improved the quality of coffee beans, as measured by raw characters and liquor tastes, when compared to coffee beans from control and *Desmodium* only treated plots.

Weed Biomass and Weed Control Efficiency

The combined application of mineral fertilizer and *Desmodium* treatments had a significant ($P\leq0.01$) effect on weed biomass. Plots treated with RMF registered significantly the highest weed dry biomass weights of 2667.0 and 2555.6 kg ha^{-1}, respectively (Figure 3a). This could be attributed to the available open space in plots promot luxurious weed growth, resulting in higher weed infestation and weed dry biomass weight. In contrast, *Desmodium* treated plots alone or in combination with inorganic fertilizer had lower weed biomass than the control and plot treated with mineral fertilizer alone (Figure 3a). The lower weed biomass observed in the *Desmodium*-treated plot could be attributed to the fact that this cover crop provides good ground cover, which has a smothering effect on weed growth and development by depriving radiant energy the target weeds in the respective experimental plot. Besides, computation for available environmental resources such as soil moisture and nutrient by *Desmodium* cover crop may have also contributed to the low weed biomass observed in *Desmodium* alone treated plots (Taye *et al*., 2008).

Similarly, application of mineral fertilizer and *Desmodium* treatments had a significant ($P\leq0.01$) impact on weed control efficiency. As a result, plots treated with 50 % RMF + *Desmodium*, 25 % RMF + *Desmodium*, and *Desmodium* alone had the highest and non-significant ($P>0.05$) weed control efficiency of 88.72, 86.67, and 83.55 %, respectively (Figure 3b). In contrast, plots treated with control and RMF had the lowest weed control efficiency of 0 and -12.74 %, respectively (Figure 3b). The highest weed control efficiency in *Desmodium* alone and combination of RMF + *Desmodium* treated plots could be attributed to good ground cover by the green manure cover crop, which deprives radiant energy for growth and development of the target grassy and broad-leaved weeds and thus resulted in lower weed density and dry weight, as well as improved weed control efficiency in the coffee farm.

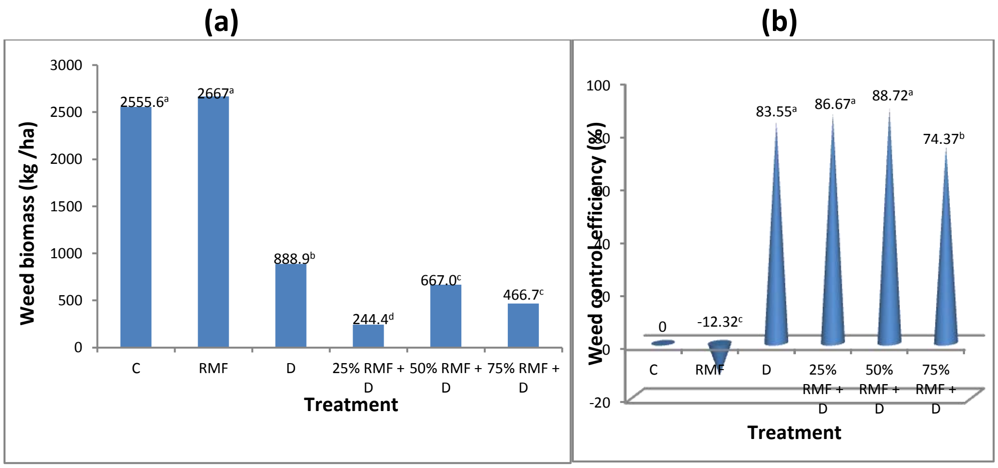


Figure 3. Effects of a combined application of mineral fertilizer and *Desmodium* on weed dry biomass weight (kg ha^{-1}) (a) and weed control efficiency (%) (b). Bars capped with same letter are not significantly different at P = 0.01 probability level. C = Control, D = *Desmodium* and RMF = Recommended rate of mineral fertilizer (172 and 63 kg ha^{-1} N and P, respectively).

Table 6. Partial budget and dominance analysis for the effect of combined use of *Desmodium* and mineral fertilizer on coffee yield.

Treatment	Unadjusted yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross benefit (Birr ha^{-1})	Variable cost (Birr ha^{-1})			Net benefit (Birr ha^{-1})	MRR (%)	Value to cost ratio	Cost dominance
				Fertilizer	Fertilizer application	Total variable cost				
Control	598.6	538.7	35015.5	0	0	0	35015.5	0		
RMF	1276.1	1148.5	74652.5	9931.1	2777.5	12708.6	61943.9	241.9	4.87	ND
Desmodium	826.6	743.9	48353.5	0	0	0	48353.5	0		
25% RMF + D	1031.8	928.6	60359.0	2482.8	694.4	3177.2	57181.8	277.9	17.99	D
50% RMF + D	1186.9	1068.2	69422.0	4965.6	1388.8	6354.4	63067.6	185.3	9.98	ND
75% RMF + D	1090.7	981.6	63804.0	7448.4	2083.2	9531.6	54272.4		5.69	D

32.00 Ethiopian Birr (EtB) = 1.00 US Dollar. Field prices of clean coffee bean, TSP and urea valued with respective prices of 65.00, 13.50 and 12.68 ETB kg^{-1}. RMF = Recommended mineral fertilizer (172 and 63 kg ha^{-1} N and P, respectively). ND = Non-dominated and D = Dominated.

CONCLUSIONS AND RECOMMENDATION

Integrated nutrient management for crop production requires quantitative information on all nutrient sources be made available. Inorganic fertilizer is the immediate source of soil nutrient for crop, while organic fertilizers maintains soil health, improves soil nutrient exchange and it mineralized within only a few cropping seasons to obtain a sustainable and stable increase in crop yield and quality.

To evaluate the effects of inorganic and/or organic nutrient sources on soil fertility is obviously to measure crop yields and quality over the long-term, because it takes years for the yield to consistently reflect improved soil fertility status. This presumably has been reflected on the soil chemical parameters in the current study. Laboratory analysis results of soil samples collected before commencement of the current experiment showed the soil is very acidic with pH of 4.90 and has low exchangeable Ca and Mg, organic C, total N and available P. However, soil samples collected at the completion of the study indicated that significant improvement in soil organic C, total N and available P by the combined application of mineral fertilizer and *Desmodium* to coffee orchards. The analysis of variance among the treatments also showed significant ($P \leq 0.05$ or $P \leq 0.01$) impact and lading performance in coffee yield and quality and weed growth. Accordingly, clean coffee yields of 1276.1 and 1186.9kg ha^{-1} were obtained from experimental plots treated with RMF and 50 % RMF + *Desmodium*, respectively. The highest weed dry biomass weights of 2555.6 and 2667.7 kg ha^{-1} were also observed for control and RMF, in that order. Furthermore, when compared to coffee beans from control and *Desmodium* alone treated plots, integrated application of mineral fertilizer and *Desmodium* significantly improved coffee bean quality as measured by raw characters and liquor tastes. Besides, the highest net benefit is 63067.60 and 61943.90 EthB, with marginal rates of return of 185.3 and 241.9 % and value to cost ratios of 9.98 and 4.85 EtB for every 1.00 EtB invested, respectively. In conclusion, based on the data obtained from this study combined fertilization of 50 % RMF and *Disodium* are recommended for Arabica coffee production to the study area and similar agro-ecology. Therefore, this technology should be demonstrated to farmers at a larger scale in the study areas as well as areas of similar agro ecologies to enhance production, productivity and quality coffee in the region. Furthermore, to develop an economically viable combination of mineral fertilizer, *Desmodium* and lime for sustainable Arabica coffee production in coffee producing areas of the country, additional research should be conducted at various coffee agro-ecologies of the country.

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