Journal of Genetic and Environmental Resources Conservation, 2014, 2(2):145-151.
www.jgerc.com

The effect of maize stover application as soil mulch on yield of Arabica coffee (*Coffee arabica* L.) and some soil properties at Chiro, Western Hararghe Zone, Ethiopia

Zelalem Bekeko

Haramaya University Chiro Campus, Department of Plant Sciences, Po box 335, Chiro, Ethiopia.
E. mail: zelalembekeko@yahoo.com, Telephone:+251911810622 Fax: +251255510182

Abstract

Coffee is the second most traded commodity next to petroleum and the most widely consumed beverage worldwide. Ethiopia is the third largest Arabica coffee (*Coffee arabica* L.) producer in the world. Coffee from the eastern part of Ethiopia is known for its Mocha flavor and fetches the most premium value on the world market. However, coffee production in this region is affected by poor soil moisture during the dry seasons and poor soil fertility status. An experiment was conducted during the dry seasons of 2008 to 2011 at western Hararghe Zone, Haramaya University Chiro Campus to determine the effect of maize stover as soil mulch on yield of Arabica coffee and its effect on some soil properties. Soil samples were taken from 0-30 cm and 30-60 cm depths before applying the mulch and 95 days after application were analyzed for soil texture, pH, CEC, total N, OC and available P. Five levels of maize stover as soil mulch at a rate of: 0t/ha, 2t/ha, 4t/ha, 6t/ha and 8t/ha were applied arranged in randomized complete block design with four replications. Data on yield were recorded during specific phenological stage of the plant. From the analysis the experimental soil was found clay loam having a CEC of 59.7cmol/kg and slightly basic showing a pH of 8.01. The soil contained 0.44%, 5.01% and 47.9 mg/kg of total N, OC and available P, respectively before mulch application and 0.41%, 8.52% and 59.3 mg/kg of total N, OC and available P, respectively after stover application. In addition a CEC of 68.7cmol/kg and pH of 7.61 were noted. The result from the application of maize stover significantly increased total yield, soil moisture reserve, CEC and improved the level of available P, while the level of N remained unchanged. Although the effect between 6t/ha and 8t/ha was not significant on bean yield of coffee, maximum soil moisture reserve was obtained at rate of 8t/ha. The result of the present study also elucidated that, the unmulched control plots had the poorest moisture reserve and lowest bean yield. While application of 8 t/ha of maize stover as a soil mulch significantly increased coffee yield and soil moisture reserve. Thus, it is recommended that sustainace of coffee production in moisture deficit parts of Hararghe areas can be achieved by applying 8t/ha of maize stover as soil mulch during the dry seasons. However, in order to make precise recommendations, extensive laboratory and field trials need to be conducted on C:N, nitrogen mineralization and its effect on soil microbial populations.

Keywords: Nitrogen, Phosphorus, CEC, Randomized Complete Block Design Maize Stover, Arabica coffee, Soil moisture, Microbial population

Introduction

Coffee is the second most traded commodity next to petroleum and the most widely consumed beverage worldwide (Vega, 2008). Ethiopia is the third largest Arabica coffee (*Coffee arabica* L.) producer in the world (IOC, 2010) and coffee is still a major contributor to Ethiopian economy and plays a key role in the livelihood of about1.5 millions of coffee growing households in Ethiopia. Over 15 million people depend directly or indirectly on coffee being involved in production, processing and marketing activities (Petit, 2007; Labouisse *et al.*, 2008). In Ethiopia coffee grows in diverse agro ecologies ranging from 1000 m.a.s.l to over 2000 m.a.s.l in its native area under the forest canopy (Labouisse *et al.*, 2008).

In Ethiopia, coffee was cultivated in this traditional way following the principles that Lammerts van Bueren and Struik (2004) called ‘the concept of naturalness’. Soils were amended by applying compost, farm yard manure and green manure, while no chemical fertilizers, herbicides or fungicides were used. It also grows in open fields as a garden plantation which accounts 20% of the total production in the country (Kufa *et al.*, 2001).

The national average yield of coffee in Ethiopia is less than 700kg/ha as compared to other east African countries and the world average yield which is more than 1200kg/ha (Labouisse *et al.*, 2007; Campanha *et al.*, 1982; Canell *et al.*, 1985). This lower yield is attributed to both biotic and a biotic factors. Poor soil fertility management, soil moisture deficit, CBD, coffee wilt disease and insect pests are some of the factors contributing to lower yield of Arabica coffee in Ethiopia (Wassu *et al.*, 2004; Adugna *et al.*, 2009). In the highlands of Hararghe areas coffee is grown as garden plantation being intercropped with different crops such as sweet potato, Chat (*Chata edulis*), banana and some other fruit crops(Damenu, 2008). However, coffee production in this region is affected by poor soil moisture regime during the dry seasons, poor soil fertility status, CBD and the expansion of Chat. Coffee from this region is known for its Mocha flavor and fetches the most premium value on the world market (Damenu, 2008).

Various attempts have been made to determine the importance of numerous factors that affect growth and bean quality in coffee agro ecosystems, including climatic conditions, shade management, fertilization regimes, mulching and adequate pruning in different coffee growing regions of the world including Ethiopia (Wintgens, 2004; Steiman, 2008; Bosselmann *et al.*, 2009; valos-Sartorio and Blackman, 2010).

Shade management ranges from coffee systems under naturally unmodified forest cover over scattered multipurpose trees to highly controlled shade in commercial agro forestry systems (Kufa *et al.*, 2001; Perfecto *et al.*, 2005; Siles *et al.*, 2010). Some work has been done to document the relationship between shade and coffee yield, e.g. Beer (1987) and DaMatta (2004) found positive effects in suboptimal locations, whereas Soto-Pinto et al. (2000) found negative effects when shade level was above 50%. Siles *et al.* (2010) found that high shade (60-80%) coffee flowers equally well to the medium-shade (30-50%) in low-input coffee farms of Chiapas, Mexico. Results differ because the environmental factors and the coffee varieties examined vary among the studies, and issues of exact environmental needs are difficult to quantify because of the variation (Carr, 2001).

Optimal shade levels are likely to be below 50%, especially for coffee that receives fertilization or supplemental irrigation. What is unknown is whether the tradeoff of yield with bean size, flavor profile, or other aspects of quality, that can occur with shade results in a net benefit to the producer. Litter fall from shade trees serve as soil mulch and contribute in yield sustainace. However, as compared to studies made on use of shade trees the role of mulch in coffee production under unshade condition is not well studied in many coffee producing countries including Ethiopia.

In unshaded coffee, mulch from grasses, wheat straw and maize stover helps to control soil erosion and weeds, preserve soil moisture and is also an important source of organic matter and nutrients (Mitchell, 1988; Anderson *et al.*, 1990; Youkhana *et al.*, 2009). For instance, the practice of applying annually large quantities (5–10 t ha−1) of mulch cut from elephant (Napier) grass (*Pennisetum purpureum*) on a plantation coffee in Kenya adds large amounts of plant nutrients to the soil, K in particular. According to the nutrient content data of various mulches and manures provided by Njoroge (2001) 10 t of mulch from elephant grass would contain 150 kgN, 26 kgP and 350 kg K, but from natural grasses or maize stover140–200 kgN, 13–15 kgP and 88–160 kg K was obtained (Njoroge, 2001; Babbar *et al.*, 1995).

However, smallholder coffee farmers in eastern parts of Ethiopia usually have no access to such large quantities and instead prefer to feed whatever is available to their livestock. Mulching of unshaded coffee is not much practiced in most other coffee producing countries including Ethiopia. Here again, it is fairly realistic to assume that more mulch is being applied where yields are higher: 10 t/ha mulch applied annually (nutrient input of 150 kg N, 26 kg P and 350 kg K) to coffee yielding 2 t ha−1 green beans and 5 t mulch at half the yield level (Njoroge, 2001).

Western Hararghe is one of the most drought prone areas of the Oromia Regional State, Ethiopia (Damenu, 2008). As a result of this coffee yield is strongly influenced by lack of soil moisture during growth, flowering, fruit setting, bean synthesis and expansion (Damenu, 2008). Soil mulch significantly contributes to alleviate these stresses. However, local farmers from the region uses sorghum and maize stover for animal feed, fuel wood and fencing which leads to poor soil organic matter build up in the zone (Ararsa , 2012). As a result the soil from this region is suffering from soil erosion, nutrient leaching and poor soil moisture regime leading poor crop productivity including coffee.

To date use of maize stover as soil mulch in sustaining coffee production and productivity in this region is not studied. Therefore, the objective of this study was to determine the effect of maize stover as soil mulch on yield of Arabica coffee and its effect on some soil properties at Chiro, Western Hararghe Zone, Ethiopia.

Materials and Methods

Description of the study area: West Hararghe is located between 7^0 55' N to 9^0 33' N latitude and 40^0 10' E to 41^0 39'E longitude. The major crops grown in the study area are sorghum, maize, chat, field beans, potato and tea. The area is characterized by Charcher Highlands having undulating slopes and mountainous in topography. The mean annual rainfall ranges from 850 to 1200 mm/year with minimum and maximum temperatures of 12^0 C and 27^0 C, respectively.

Treatment Details: Maize stover was harvested at the physiological maturity of maize and chopped at a size of 75cm long and weighed using a spring balance to determine the amount of mulch material required by each plot. Five levels of maize stover as soil mulch at a rate of: 0t/ha, 2t/ha, 4t/ha, 6t/ha and 8t/ha were applied arranged in randomized complete block design with four replications at the Haramaya University Chiro Campus, Western Hararghe Zone from 2008 to 2011.

Experimental Procedures: The already existing coffee plantation in the Campus was used as a test plant. A plot size of 6 m length by 5 m width with three rows per plot was used. Spacing was 2 m and 1.8 m between rows and plants, respectively. Urea at a rate of 150kg/ha was applied to each experimental plot on 15 June 2008, 10 June 2009, 15 June 2010 and 5 June 2011and maize stover was applied to each plot based on the specified rate/ha for four years at the end of the main rainy season for each year(after mid- September in all years).

Forty-six surface soil samples (0-30cm and 30-60cm depths) were collected from representative spots of the entire experimental field after final fertilization and composited into two replicate samples for each analysis (Wilson, 1985). These were analyzed for soil texture, pH, CEC, organic carbon, available P and total N. Similarly, surface soil samples at the same depth were collected at blooming stage (75 days after mulch application). One representative soil sample was taken from every plot, using auger to make composite sample per treatment for the analysis of total N and available P (Wilson, 1985).

Soil texture was expressed by using Bouyoucos hydrometer method (Day, 1965). Available P was extracted with a sodium bicarbonate solution at pH 8.5 following the procedure described by Olsen et al. (1954). The pH of the soil was measured potentiometrically in the supernatant suspension of a 1:2.5 soil: water mixture by using a pH meter, and Organic Carbon was determined by following Walkely and Black wet oxidation method as described by Jackson (1958). Cation Exchange Capacity (CEC) was measured by using 1M-neutral ammonium acetate. Total Nitrogen was determined by using Kjeldahl method as described by Jackson (1958).

In order to record the soil profile characteristics at the experimental site a 2m by 1.5m and1.60m deep pit was excavated adjacent to the experimental field and soil profile was described in situ. Soil samples were taken from all the identified horizons and pH, texture, organic matter content, total N, available P and CEC were analyzed using the same procedures. Bulk density, particle density and pore spaces were also determined.

AT maturity dried coffee beans were collected from each plot and manually hulled to get a clean coffee. The recorded yield per plot was converted to yield per hectare basis. An area of 15 m^2, corresponding to 4 plants in the central two rows, were picked immediately after physiological maturity for bean yield. During harvests, border plants at the ends of each row were excluded to avoid border effects. Coffee moisture percent (mc %) was estimated using a Dickey-John multi grain moisture tester. Grain yield (GY t ha-1) was calculated using picked coffee beans and adjusted to12% moisture.

Statistical Analysis: The data recorded in this study were subjected to statistical analysis (SAS version 9.0). Analyses of variance were carried out using MSTATC software. Significant differences between and or among treatments were delineated by Least Significant Differences (LSD).

Results and Discussion

Result from the analysis of variance on mean yield of coffee beans over the four seasons showed the existence of significant differences among treatments (Table 1). Mean bean yield ranged from 520 kg/ ha to 1070 kg/ ha over four years. The highest mean yield 1070 kg/ ha was observed in 2009 and the poorest yield (520kg/ha) was noted in 2010. The overall Result from the pooled analysis of variance on bean yield of Arabica coffee from the present study revealed that there exists a significant difference (P<0.05) among treatment over the seasons (Table 1 and Appendix Table 1).

Table (1): Effect of maize stover as soil mulch on yield of Arabica coffee (kg/ha) clean coffee (mean value) at Chiro, Western Hararghe 2008 to 2011 cropping seasons

	Replication				
Treatment	I	II	III	IV	Total
0t/ha	564	487	545	526	2122
2t/ha	547	523	520	553	2143
4t/ha	618	642	653	629	2542
6t/ha	961	979	943	984	3894
8t/ha	1062	1054	1070	1063	4249
Total	3752	3685	3731	3755	14923
LSD=0.05	122.06				
CV (%)	11.89				

This study also indicated application of maize stover as soil mulch on coffee trees increased the bean yield of coffee trees over years and significantly reduced weed infestation and increased soil moisture reserve. The result also showed the existence of no significant difference between 6t/ha and 8t/ha on coffee bean yield. But the highest soil moisture was reserved at a rate of 8t/ha. Similarly application of maize stover at a rate of 2t/ha and the unmulched plots showed no significant differences on bean yield of coffee trees. However, slight variations were observed in weed suppression effect and soil moisture reservation.

Soil texture and soil chemical analysis: Result from this experiment also showed that the texture of the soil from the area was found clay loam having a CEC of 59.7cmol/kg and slightly alkaline showing a pH of 8.01 (Table 2). The soil also contained 0.84%, 5.01% and 47.9mg/kg of total N, O, C and available P, respectively, during pre-mulching. Available P content of the soil increased with increase of maize stover application rates up to 20kg P/ha and then showed slight decline (Table 2).

The values of total N, analyzed from composited soil samples, per treatment tended to remain almost the same irrespective of different levels of stover application (Table 2). Total N content of the soil before mulching was 0.44% and at 95 days after mulching, the values varied from 0.41 to 0.44%. This might be due to the mobility of N in soil, particularly due to high rainfall recorded during the crop season and competition of soil microorganism during decomposition period resulting in high C: N ratio.

Application of maize stover as soil mulch during the experimental seasons resulted in modification of soil porosity level, decrement of soil pH, increment of soil organic carbon and CEC. But no change was observed on soil texture, percentage soil nitrogen level and soil densities (Table 3).

Application of mulch on coffee soils help in maintaining soil temperature and the soil moisture reserve by decreasing evapotranspiration from the surface soil which contribute to generation of greater number of fruits per node and nodes per lateral branches produced under full-sun responsible for the greater yield of coffee in this study; and this was contrary to other results (Campanha *et al.*, 2004; Wintgens, 2004; Morais *et al.*, 2006). However, some other reports have suggested that coffee plants that receive more sunlight with judicious level of soil mulch can produce a greater number of flowers (Beer *et al.*, 1998; Lin, 2008 and 2009) because of more number of nodes formed per lateral or more flower buds existing at each node (Wintgens, 2004).

In the present study bean yield of Arabica coffee was significantly increased as the rate of maize stover application as soil mulch increased (Table 1). The highest bean yield (1070 kg/ha) was obtained at 8t/ha followed by 6t/ha (Table 1). Application of maize stover contributed a yield advantage of 550 kg/ha over the unmalched plots. This can be owing to the effect of the stover in reducing soil moisture loss, maintainace of soil temperature and addition of nutrients. Njoroge *et al.* (2001) reported that the bean yield of Arabica coffee from Kenya was found to be 1.2 t/ha to over 2 t/ha) when 10t/ha mulch is applied. Therefore, the present finding is in agreement with this report. But a significant difference in coffee yield was observed during the experimental seasons over years indicating the poorest yield record in 2009 and 2011. This might be due to variation in environmental differences among the growing seasons, the response of the coffee trees to the environment and G x E.

Table (2): Some chemical and physical properties of soil at Chiro, western Hararghe (2008 to 2011) before maize stover application as soil mulch

Depth (cm)	Hori zon	Particle size distribution (%)			Textural class	PD g(cm^3)	BD g(cm^3)	PS (%)	pH	OC (%)	Total N(%)	Av.P (ppm)	CEC Cmol/ kg
		Clay	Sand	Silt									
0-30	AP	50	38	12	clay	2.38	0.99	57.9	8.01	0.44	0.45	37.9	59.71
30-60	Bt1	18	56	26	sand	2.50	1.38	46.8	8.45	0.48	0.56	34.8	-
60-90	Bt2	20	54	26	sand	2.50	1.34	46.4	8.78	0.45	0.34	33.8	-

PD= particle density, *BD*= bulk density, *PS*= percent porosity, *OC*= organic carbon, *AV.P*=available phosphorus, *CEC*= cation exchange capacity,

Table (3): Effect of maize stover as soil mulch on some physical and chemical properties of soil 95 days after application at Chiro, Western Hararghe zone 2008 to 2011 cropping seasons (mean values)

Depth (cm)	Hori zon	Particle size distribution (%)			Textural class	PD g(cm^3)	BD g(cm^3)	PS (%)	pH	OC (%)	Total N(%)	Av.P (ppm)	CEC Cmol/kg
		Clay	Sand	Silt									
0-30	AP	50	38	12	clay	2.38	0.99	67.2	7.61	5.03	0.44	59.3	68.70
30-60	Bt1	18	56	26	sand	2.50	1.38	48.5	7.55	0.78	0.56	34.8	-
60-90	Bt2	20	54	26	sand	2.50	1.34	52.0*	7.70	0.54	0.34	33.8	-
BAP								67.2		5.03	0.44	37.9	59.71
AP								75.5*		8.52*	0.43	59.3*	68.70*

PD= particle density, *BD*= bulk density, *PS*= percent porosity, *OC*= organic carbon, *AV.P*=available phosphorus, *CEC*= cation exchange capacity, BAP= before application of maize sover, AP= after application of maize stover

In Kenya according to the nutrient content data of various mulches and manures provided by Njoroge (2001) 10 t of mulch from elephant grass would contain 150kg N, 26kg P and 350kg K, but from natural grasses or maize stover 140–200kg N, 13–15kg P and 88–160kg K were obtained. For instance, the practice of applying annually large quantities (5–10 t ha−1) of mulch cut from elephant (Napier) grass (*Pennisetum purpureum*) on a plantation coffee in Kenya adds large amounts of plant nutrients to the soil, K in particular. But in this present study the status of K in soil during the experimental seasons was not studied and the level of soil N remained unchanged over four years. This might be due to the increase in soil organic carbon percentage (Table 3). However, the level available P has increased in the treated plots suggesting the existence of consistent finding with the reports of Njoroge (2001) in which mulch from grasses contributed an additional value of 26kg/ha P. Therefore, the present finding is in agreement with these reports. The application of maize stover at the rate of 8t/ha resulted in highest bean yield, which was significantly higher than maize stover applied at the rates of 0, 2 and 4t/ha, while it was statistically at par with bean yield obtained at 6t/ha (Table 1 and Appendix Table 1).

In addition application of 8t/ha increased bean yield by 352 kg/ha as compared to the control treatment implying use of maize stover as soil mulch at Western Hararghe areas help in boosting coffee productivity which is in agreement with the reports of Njoroge *et al.* (2001) who stated application of napir grass increases bean yield of Arabica coffee under moisture deficit areas.

Application of maize stover as soil mulch during the experimental seasons also resulted in modification of soil porosity level, decrement of soil pH, increment of soil organic carbon percentage and CEC (Table 3). But no change was observed on soil texture, percentage soil nitrogen level and soil densities as compared with pre mulch application results (Table 3). This might be due to mulch increases soil acidity through addition of organic compounds and phenols which leads to decrease in soil pH and enhancement of CEC. Wilson (1985) reported coffee soil under mulch condition showed slight modification in soil pH. Hence, the present finding is in agreement with his report.

Conclusions

Results of the present study indicated that, application of 8t/ha of maize stover as soil mulch has resulted in the highest bean yield of Arabica coffee at Chiro contributing a yield advantage of 550kg/ha over the unmulched plots and improved some chemical properties of the soil as well as its moisture holding capacity. However, in order to make precise recommendations, extensive laboratory and field trials need to be conducted on C: N, nitrogen mineralization and its effect on soil microbial populations.

Acknowledgements

The author is grateful to the Ministry of Agriculture and Rural Development of the Federal Democratic Republic of Ethiopia Chiro ATVET College for funding this research project, the Ethiopian National Soil Laboratory for Soil analysis, Professor Temam Hussein for his technical advice during the field experiment, Professor M.S. Hooda from the Haramaya University for his sound comments on the article and proof reading, Belay Dinsa, Ararsa Gudissa, Bacha Reda, and Tadesse Bedada for their assistance during the field data collection.

References

Anderson, J.M. and Ingram, J.S.I. 1990. Tropical soil biology and fertility: A handbook of 434 methods. Wallingford, UK: CAB Int.

Ararsa G. 2012. GIS based land suitability evaluation for sustainable agricultural development at Kuni (Sebale) watershade West Hararghe Zone, Oromia. M.Sc. thesis Mekele University, Ethiopia.

Babbar, L.I. and Zak, D.R. 1995. Nitrogen loss from coffee agro ecosystems in Costa Rica: leaching and denitrification in the presence and absence of shade trees. Journal of Environmental Quality 24:227–233.

Beer, J. W. 1987. Advantages, disadvantages and desirable characteristics of shade trees for coffee, cocoa and tea. Agroforestry Systems 5:3–13.

Bosselmann, A.S., Dons, K., Oberthur, T., Olsen, C.S., Raebild, A. and Usma, H. 2009. The influence of shade trees on coffee quality in small holder coffee agro forestry systems in Southern Colombia. Agriculture, Ecosystems and Environment 129: 253–260.

Campanha, M.M., Santos, R.H.S., de Freitas, G.B. Martinez, H.E.P., Garcia, S.L. and Finger, F.L. 2004. Growth and yield of coffee plants in agro forestry and monoculture systems in Minas Gerias, Brazil. Agro forestry Systems 63: 75-82.

Cannell, M.G.R. 1975. Crop physiological aspects of coffee bean yield: a review. J Coffee Res. 5: 7–20.

Cannell, M. G. R. 1985. Physiology of the coffee crop. In Coffee: Botany, Biochemistry and Production of Beans and Beverage, 108–124 (ed., M. N. Clifford and K. C. Willson). London: Croom Helm.

Carr, M.V. 2001. The water relations and irrigation requirements of coffee. Exp. Agric. 37:1-36.

Da Matta, FM 2004. Ecophysiological constraints on the production of shaded and unshaded coffee: a review. Field Crops Research 86: 92–114.

Damenu, 2008. Coffee production and marketing in Oromia. In coffee diversity and knowledge, Ethiopian Institute of Agricultural Research.

IOC, 2010. Coffee market report, Letter from the executive director.

Kufa, T. and Shimber, T. 2001. Organic coffee production: hope for small-scale farmers in Ethiopia. In: Proceedings of the 19th International Scientific Colloquium on Coffee, Trieste, 14–18 May 2001.

Jackson, ML 1958. Soil Chemical Analysis Practice Hall of India. New Delhi.

Labouisse, JP B Belleachew S Kotecha and B Bertrand (2008). Current status of

Coffee, (Coffee Arabica) genetic resource in Ethiopia: Implication for conservation Genet. Resour.Crop Evol., 55:1079-1093.

Njoroge, J. M. 2001. Advances in coffee agronomy. In Proceedings of the International Scientific Symposium on Coffee December4, 2000, CBI-CCRI Bangalore India. 104–119.

Olsen, SR CV Cole FS Watanabe and L A Dean (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USA Circular 939: 1- 19.

Perfecto, I., Vandermeer, J., Mas, A. And Soto Pinto, L. (2005). Biodiversity, yield and shade coffee certification. Ecological Economics 54: 435–446.

Petit, N. 2007. Ethiopia's coffee sector: bitter or better future. J. Agrarian Change.7:225-263.

SAS, Institute Inc. 1990. SAS/STAT user's guide. Version 9. 4th ed., SAS Institute Inc, Cary, NC, USA.

Siles, P., Harmand, J. and Vaast, P. 2010. Effects of *Inga densiflora* on the microclimate of coffee (*Coffea arabica* L.) and overall biomass under optimal growing conditions in Costa Rica. Agro forestry Systems 78 (3): 269-286.

Soto-Pinto, L., I. Perfecto, J. Castillo-Hernandez, and Caballero-Nieto, J. 2000. Shade effect on coffee production at the northern Tzeltal zone of the state of Chiapas, Mexico. Agriculture, Ecosystems & Environment 80:61-69.

Vaast, P., Bertrand, B., Guyot, B. and Genard, M. 2006. Fruit thinning and shade improve bean characteristics and beverage quality of coffee (Coffea arabica L.) under optimal conditions. Journal of the Science of Food and Agriculture 86 (2): 197-204.

Valos-Sartorio, B.A. and Blackman, A. 2010. Agroforestry price supports as a conservation tool: Mexican shade coffee. Agroforestry Systems, 78: 169–183.

Wassu, M. Bayetta, B Harjit, S. 2004. Hetrosis and combining ability for yield and yield related trait in Arabica coffee. M.Sc. Thesis Haramaya University, Ethiopia.

Wilson, K. C. 1985. Mineral nutrition and fertiliser needs. In Coffee: Botany, Biochemistry and Production of Beans and Beverage, 135–156 (ed., M. N. Clifford and K. C. Willson). London: Croom Helm.

Wintgens, J. N. 2004. Coffee: Growing, Processing, Sustainable Production. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, pp 976.

Youkhana, A. and Idol, T. 2009. Tree pruning mulch increases soil C and N in a shaded coffee agro ecosystem in Hawaii. Soil biology and Biochemistry 41, issue 12: 2527-534.

Appendix Table (1): Analysis of Variance for the effect of maize stover applied as soil mulch on Arabica coffee yield (kg/ha) at Chiro, Western Hararghe from 2008 to 2011.

Sources of variation	df	SS	MS	F_{cal}	F_{tab}
Treatment	4	339680.25	84920.06		
Replication	3	626.55	208.85		
Error	12	75323.75	6276.979	13.53*	3.26
total	19	415630.55			
CV (%)				11.89	
LSD=0.05				122.06	