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Effect of stage at termination of legume green manures on soil organic carbon, yield and economic performance of subsequent maize crop

Tamiru Hirpa*

Hawassa University, College of Agriculture P.O. Box 5, Hawassa, Ethiopia

***Corresponding author e-mail:** *thirpa2002@yahoo.com*

KEYWORDS

Dry matter;
grain yield;
organic C;
partial budgeting;
yield attribute.

ABSTRACT

The rapid growth of population and reduction in productive agricultural lands are forcing smallholder subsistence farmers of Ethiopia to adopt intensive farming systems, to which they respond by growing more and more cereals in place of traditional fallow practices, causing widespread soil degradation. In this regard, systematic soil incorporation of N_2-fixing legume crops as a green manure could be an important agronomic approach in order to reduce the need for costly external inputs and improve internal resources for sustainable production. Two consecutive experiments were conducted in the cropping seasons of 2007 and 2008 at Assosa area, western Ethiopia, to determine the effects of stages at incorporation of four legume crops on biomass input, soil organic C content and the agro-economic performance of succeeding maize crop. Factorial combination of four legume crops and four residue managements were laid in randomized complete block design (RCBD). Among the legume crops, cowpea has recorded the highest number and fresh mass of total and effective nodules than the rest, particularly at mid-flowering stage of growth. Cowpea and pod-setting stage of growth gave the highest dry matter (DM) input that improved the organic C content of the soil. Total DM and grain yields of maize crop in the subsequent season were also significantly affected by main effects, legume species and residue management ($P \leq 0.01$). In this regard, cowpea and delayed incorporation increased the DM and grain yields of the subsequent maize crop, attributable to the differential green manure biomass yield and corresponding improvement of the soil-plant environment. This is corroborated in the present study, by highly significant positive relationships observed between soil organic C content and DM ($r = 0.88^{**}$) and grain yield ($r = 0.80^{**}$) of maize crop. The economic evaluation revealed that the highest net benefits were obtained from cowpea green manure and pod-setting stage of growth.

Introduction

The flow of nutrients in and out of agricultural systems is generally characterized by lower storage capacity, less cycling efficiency, continual loss and net removal of nutrients, unlike natural systems where biomass production is in equilibrium with nutrient reserves (Hendrix *et al*., 1992; Nair, 1996). The prevailing farming system of Assosa areas, located in western part of Ethiopia, is predominantly rainfed sorghum, maize, *tef*, finger millet, *nug* and few root crops in conjunction with rearing of livestock. The soils of the areas are low in fertility especially in N, P and organic matter. The trend of growing cereals continuously on all arable lands in the areas is undoubtedly further depleting the nutrients in the soil which are already low. The sustainability of such agricultural systems is, therefore, greatly dependent on optimizing the balance between inputs and outputs of nutrients. The use of inorganic fertilizers, to alleviate the problems of low soil fertility for successful crop production in Assosa areas, is limited by high costs and unreliable availability of inorganic fertilizers; even the few farmers who use fertilizers cannot afford recommended rates. Therefore, it is necessary to seek for affordable and less risky soil nutrient management practices.

Integration of N-fixing legumes as green manure, in this regard, offers an economically attractive and ecologically sound alternative means of reducing external inputs and improving internal resources (Bohlool *et al*., 2004). Inclusion of green manuring (GM) legumes in cereal based cropping systems have been reported in various parts of the world to result in significant inputs of N into the soil-plant system, leading to increased yields of the subsequent cereal crops (Boddey *et al*., 1997; Fillery, 2001; Ramos *et al*., 2001; Cobo *et al*., 2002).

Most studies reported so far about the effects of GM on subsequent crop focus on green manure crops incorporated at a certain growth stage. Manipulation of residue quality through proper selection of green manure crops and timing of tillage (soil incorporation) may provide practical information about changes in the quantity and quality of green mass during the growing season; the effects on soil quality indicators and succeeding crops are lacking, however. For this reason, studying about the effects of growth stage at incorporation of green manure crops on leguminous DM input, soil organic matter content and the yield performance of succeeding main crop is considered to provide much more meaningful information on selection of appropriate GM crop and development of residue management strategies. Hence, the present study was initiated with the objective to determine the effects of growth stages at incorporation of different GM legumes on soil organic C, yield and economic return of the succeeding maize crop in cereal-based cropping systems of Assosa area.

Materials and Methods

Description of the study area

The two consecutive studies were carried out on fixed plots in 2007 and 2008 cropping seasons at the experimental site of the Assosa Research Center, western Ethiopia. According to the classification of EARO (1999), the agro-climate of the area falls under sub-humid lowland with a mono-modal rainfall pattern. The annual precipitation during the 2007 and 2008 crop seasons were 1392.9 and 1452.0 mm, respectively, and the annual mean maximum temperature reaches 27.8 ^{0}C while the mean minimum temperature is 15.5 ^{0}C (Figure 1). The dominant soil at and around the Research Center is reddish brown, Nitosols, which according to pre-sowing soil test results, is low in fertility especially in N, P and organic matter (Table 1).

Experimental treatments and procedures

Factorial combination of four legume crops, namely cowpea (*Vigna unguiculata*), soybean (*Glycine max*) and two common bean (*Phaseolus vulgaris*) varieties (Black Dessie and Awash Melka) and four residue managements containing three growth stages at soil incorporation (mid-vegetative, mid-flowering and pod-setting) and unincorporated (grown for grain), plus weed fallow and *tef* (*Eragrostis abyssinica*) crop representing the farmers' practice were used. Total of 18=[(4 × 4) + 2] treatments were applied on fixed plots of 27 m^2 (4.5 m x 6 m) size each in the cropping seasons of 2007 and 2008. The experiment was laid out in two factors RCBD replicated three times.

Legume crops grown in uniform inter- and intra-row spacing of 40 cm by 10 cm, respectively, were incorporated at their three respective growth stages after mowing and chopping of the biomass to facilitate soil mixing and decomposition. In the subsequent season, maize crop was grown on the above mentioned plots to investigate the effects on the subsequent crop. Maize seeds were hand sown at intra- and inter-row spacing of 30 and 75 cm, respectively. In this study, no chemical fertilizer was applied to the crop to accord with farming practiced mostly in the area; however, the crops were raised according to the standard cultural practices applicable to the area.

Sampling and analysis of legume

Biomass and soil

To determine production of total and effective nodulation (nodules which developed pink-brown internal color when slice opened); nodule count and fresh weight data were taken after careful uprooting of 5 randomly taken plants from each plot at the respective termination stage. Shoot materials of GM legumes at respective growth stages from 1 x 1 m quadrant were sampled from net plot and dried in an oven at 70 °C for 48 hours to determine the DM input.

Soil sampling at plow depth of 0-20 cm was done twice; before planting of legumes and right before the maize planting after incorporation of the legumes. Samples collected before and after incorporation of GM were air dried, crashed and sieved for the analysis of organic C content by oxidation with potassium dichoromate in a sulphuric acid medium (Nelson and Sommers, 1996).

Determination of agro-economic performances of succeeding maize

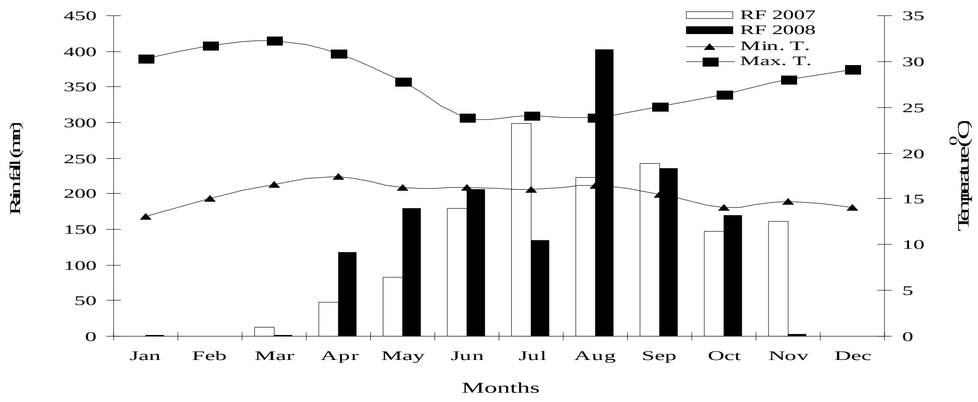
Dry matter yield, cob length (cm), number of cobs/m^2, 1000 seeds weight, and total grain yield were the yield and yield components of maize crop studied in the present study. Five plants were randomly taken from the middle rows of each plot for the measurements. Total grain production was determined by extrapolating the net plot yield to per hectare basis.

The economic evaluated was done to decide which GM legume crop and what stage of green manure termination timing produced better yield of the succeeding maize crop to justify the adoption of this system by the farmers. In this regard, the average yield of treatments was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. To estimate economic

Table.1 Pre-planting soil test results

Parameters	Soil test values
pH (H_2O)	5.9
Organic C (g C kg^{-1})	19.73
Total N (g kg^{-1})	1.4
Available P (mg kg^{-1})	1.84
EC (dS/m)	0.14
CEC (Cmol(+)/kg)	25
K (mg kg^{-1})	37.14
Ca (Cmol(+)/kg)	6.34
Mg (Cmol(+)/kg)	3.67
Na (Cmol(+)/kg)	0.16
Base Sa. (%)	40.6

Figure.1 Monthly mean minimum and maximum temperature (^{0}C) and rainfall (mm) data of the 2007 and 2008 in Assosa area



RF = Rainfall; T = Temperature.; Source: Assosa Metrological Service Branch Office.

Table.2 Interaction effects of green manure crops by growth stage on number of total nodules per plant

Green manure crop (GMC)	Growth stage (GS)†			Mean
	Mid-vegetative	Mid-flowering	Pod-setting	
Cowpea	3.2cd	5.8a	5.2ab	4.7
Black Dessie	2.3c-e	1.9de	1.4e	1.9
Awash Melka	2.2c-e	1.1e	1.1e	1.5
Soybean	3.5cd	3.9c	3.4c-e	3.3
Mean	2.8	3.2	2.5	
LSD	GMC × GS			
(0.01)	NS			
(0.05)	1.72			

*Interaction means followed by the same letter are not significantly different at the specified probability level. †FW = Fresh weight; GMC = Green manure crop; GS = Growth stage; NN = Number of nodules; NS = Non-significant parameters, products were valued based on market price collected from local market. The economic analysis, comprising a partial budget with dominance and marginal analysis, was carried out as described in CIMMYT (1988).

Data analysis

The data collected during the course of the two consecutive experiments were subjected to analysis of variance using MSTATC computer software. Treatments that showed significant effects on parameters considered at 95 and 99% confidence intervals were further separated using least significant difference (LSD) test.

Result and Discussion

Legume nodulation pattern, dry matter input and subsequent soil organic C

In the present study, significant ($P \leq 0.05$) combined effect of green manure crop type by growth stage treatments was observed in number of total number of lateral nodules, whereby cowpea at mid-flowering stage of growth recorded the top rank, and declining trends were observed for the rest species in the subsequent samplings (Table 2), ascribable to genetic variation to N_2-fixing ability involving both legume type and rhizobium components of the symbiotic association (Hungria and Bohrer, 2000; Sanginga *et al*., 2000).

A trend similar to number of total nodules was also observed in nodule fresh mass while considering the effects of species variability and growth stage. Similar results were reported by Elahi *et al*. (2004) who observed decline in number and fresh weight of nodules after flowering stage of growth in mungbean cultivars.

Significant ($P \leq 0.05$) interaction effect of legume type by growth stage treatments was also observed both in number and fresh weight of effective nodules, whereby a trend similar to total nodules were observed (Table 3). Generally declining values of indirect measures of N_2-fixation (nodulation pattern) after flowering stage of growth have been documented extensively (Johnson and Hume, 1983; Lawn and Brun, 1984; Wolyn *et al*., 1989).

Total DM input of GM crops was significantly different ($P \leq 0.01$), where the highest amount was recorded by cowpea (1.87 t ha^{-1}) followed by soybean (1.43 t ha^{-1}) when averaged across termination stages (Table 4). The marked difference in the DM yield of legumes may be attributable to species variability (Uratani *et al*., 2004). Significant ($P \leq 0.05$) effect of growth stage at termination of GM legumes was also observed with regard to total DM input, in which DM increased as termination was delayed from mid-vegetative to mid-flowering and to pod-setting stages of growth (Table 4).

Similarly, Brandt (1996) found the average biomass of black lentil to double from early bud to full-bloom stages. Hence, delaying incorporation of green manures to a pod-setting stage of growth could be considered as effective strategy, as GM crops produced higher leguminous phytomass at this stage of growth. Similarly, Kelling *et al*. (2001) stated that legumes to be considered as effective green manure crop for succeeding crops; they must supply sufficient biomass and must release the legume N to fill the demand.

Laboratory test results of the initial soil and soil after legume incorporation showed that highly significant differences among legume treated plots and the control treatments with respect to organic C content of the plow depth (0-20 cm); while higher soil C values were obtained after GM of legume crops (Tables 5). Moreover, the difference between the legume type was highly significant, whereby plots treated with cowpea and soybean improved soil organic C over the initial by 20.57 and 16.88%, respectively.

The effect of growth stages at incorporation on soil organic C content was also significant. An overall increase of soil organic C by 17.48% over the mid-vegetative stage was recorded, when the legume crops were left to pod-setting growth stage (Table 5). The building up of soil OM was found to be determined by the length of the growing season or the amount and maturity of the phytomass. Concomitant to this result, Kou *et al*. (1997) and Sainju (2005) found that the amount and type of green manures added to the soil determines the levels of soil organic C.

Generally, as incorporation delays, DM production and corresponding organic C content of soil increased. Young material incorporated at mod-vegetative stage contributed little to the soil OM formation, attributable to the limited biomass and rapid microbial degradation or loss of residue materials by decomposition (Njunie *et al*., 2004).

Koopmans and Goldstein (2001) made a similar statement that if the green manure is left to grow in the field for a longer period, it will form more biomass, when worked into the soil such mature material will do a much better job in forming soil OM.

The organic C content of the soil in the green manure treatments was found to be directly related (r = 0.71*) to the amount of leguminous phytomass added into soil (Figure 2). This provides a solid credence to the premise that the buildup of soil organic matter is largely affected by the quantity of the DM added to the soil. Similar to our results, other workers (Rasmussen *et al*., 1980; Jenkinson and Ladd, 1981) have observed linear relationship between changes in soil organic C and the amount of plant residue applied to the soil. Recent reports (Koopmans and Goldstein, 2001; Kuo and Jellum, 2002), on the other hand, have pointed out that formation of soil OM is largely determined by the amount and quality of the residues that are incorporated into the soil.

While considering plots where legume crops were grown for grain, where only pods were harvested (removed) and the stover were left in the field unincorporated, the mean soil organic C content was found to be higher than that of incorporation at mid-vegetative stage. In this regard, the mean of legume crops grown for grain improved the organic C content of the soil by about 6.59 and 3.19% over the initial soil and *tef* stubble, respectively. This result is concomitant with results reported by long-term studies of Wani *et al*. (1996) and Rego and Rao (2000) on cowpea, pigeon pea and chickpea grown in rotation with sorghum and safflower that showed increased organic C contents of the soils in treatments having legumes.

Effect on yield components of subsequent maize

The number of maize cobs per m^2 in the present study were significantly affected ($P \leq 0.05$) by the green manuring species. When averaged across incorporation stages, among the green manure crops, cowpea treated plots produced the highest number of cobs, while maize after *tef* recorded the least (Table 6). In other words, green manuring of cowpea increased number of

Table.3 Interaction effects of green manure crop type by growth stage on number (NN) and fresh weight (FW) of effective nodules per plant

Green manure crop (GMC)	Growth stage (GS)†			Mean
	Mid-vegetative	Mid-flowering	Pod-setting	
Nodule number (NN)/plant				
Cowpea	0.13a-c	0.21a	0.16ab	0.17
Black Dessie	0.10bc	0.00d	0.00d	0.03
Awash Melka	0.10bc	0.00d	0.00d	0.03
Soybean	0.22a	0.18ab	0.07cd	0.15
Mean	0.14	0.10	0.06	
Fresh weight (FW) of nodules/plant				
Cowpea	1.2b-d	2.2a	1.9ab	1.8
Black Dessie	0.9c-e	0.0e	0.0e	0.3
Awash Melka	0.9c-e	0.0e	0.0e	0.3
Soybean	1.7a-c	1.9a-c	0.7de	1.4
Mean	1.2	1.0	0.6	
LSD	NN (GMC × GS)	FW (GMC × GS)		
(0.01)	NS	NS		
(0.05)	0.09	0.97		

*Interaction means followed by the same letter are not significantly different at the specified probability level.

†FW = Fresh weight; GMC = Green manure crop; GS = Growth stage; NN = Number of nodules; NS = Non-significant

Table.4 Effects of growth stage on total dry matter production (t ha^{-1}) of the green manure crops

Green manure crop (GMC)	Growth stage (GS)†			Mean*
	Mid-vegetative	Mid-flowering	Pod-setting	
Cowpea	1.60	2.10	1.90	1.87a
Black Dessie	0.61	0.78	1.24	0.88c
Awash Melka	0.90	0.93	0.94	0.92c
Soybean	1.21	1.33	1.74	1.43b
Mean*	1.08b	1.28ab	1.46a	
	GMC	GS	GMC × GS	
LSD (0.01)	0.43	NS	NS	
(0.05)	-	0.27	NS	

*Means within a row or a column followed by the same letter are not significantly different at the specified probability level.

†GMC = Green manure crop; GS = Growth stage. NS = Non-significant.

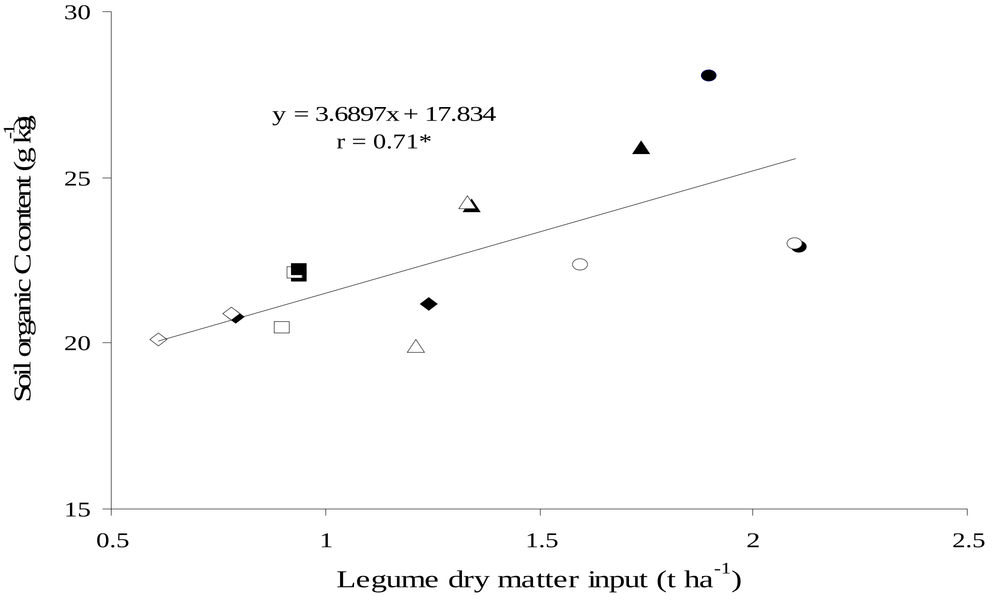
Table.5 Effects of growth stages of green manure crops at incorporation on soil organic C content (g kg^{-1})

Green manure crop (GMC)	Growth stage at incorporation (GSI)†			Un-incorporated	Mean*
	Mid-vegetative	Mid-flowering	Pod-setting		
Initial soil	-	-	-	-	19.73e
Tef stubble	-	-	-	-	20.38d
Weed fallow	-	-	-	-	20.91c
Cowpea	22.33	23.00	28.04	21.81	23.79a
Black Dessie	20.13	20.87	21.17	21.16	20.83c
Awash Melka	20.44	22.13	22.23	18.94	20.94c
Soybean	19.93	24.23	25.89	22.20	23.06b
Mean*	20.71c	22.55b	24.33a	21.03bc	
	GMC	GSI	GMC × GSI		
LSD (0.01)	0.43	NS	NS		
(0.05)	-	0.67	NS		

*Means within a row or a column followed by the same letter are not significantly different at the specified probability level.

†GMC = Green manure crop; GSI = Growth stage at incorporation; NS = Non-significant.

Figure. 2 Relationship between dry matter productions (t ha^{-1}) of legume crops (o = cowpea; □ = Black Dessie; ◊ = Awash Melka; Δ = soybean) incorporated at different times (open cells = at vegetative stage; shadowed cells = at flowering stage; filled cells = at pod setting stage) and soil organic C content (g kg^{-1} soil).



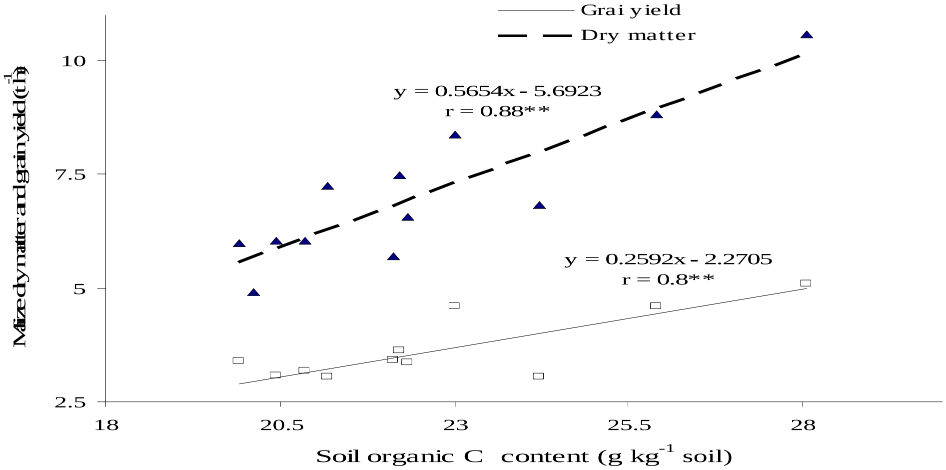
* = Significant at P $\leq$ 0.05 probability level.

Table.6 Effects of green manure legume crops incorporated at different growth stages on number (m^{-2}) and length (cm) of maize cob

Green manure crop (GMC)	Growth stage at incorporation (GSI)†			Un-incorporated	Mean*
	Mid-vegetative	Mid-flowering	Pod-setting		
Number of maize cobs m^{-2}					
Tef stubble	-	-	-	-	3.37c
Weed fallow	-	-	-	-	3.70bc
Cowpea	4.0	4.6	5.7	3.6	4.48a
Black Dessie	3.7	3.4	4.1	3.5	3.68bc
Awash Melka	3.3	3.9	4.8	3.7	3.93ab
Soybean	3.7	4.0	4.7	4.1	4.13ab
Mean*	3.67b	3.98b	4.83a	3.73b	
	GMC	GSI	GMC × GSI		
LSD (0.01)	NS	0.6	NS		
(0.05)	0.51	-	NS		
Cob length (cm)					
Tef stubble	-	-	-	-	13.67
Weed fallow	-	-	-	-	13.74
Cowpea	15.3	15.7	16.2	14.0	15.30
Black Dessie	12.8	13.6	14.6	13.4	13.60
Awash Melka	12.5	13.2	15.3	13.2	13.55
Soybean	14.7	14.6	15.5	16.3	15.23
Mean*	13.83b	14.28ab	15.40a	14.23ab	
	GMC	GSI	GMC × GSI		
LSD (0.05)	NS	1.43	NS		

*Means within a row or a r column followed by the same letter are not significantly different at the specified probability level.†GMC = Green manure crop; GSI = Growth stage at incorporation; NS = Non-significant.

Figure.3 Relationship between total soil organic C content (g kg^{-1}) and dry matter and grain yield (t ha^{-1}) of succeeding maize crop as affected by green manuring



** = Significant at $P \leq 0.01$ probability level.

Table.7 Effects of green manuring legume crops and stage at incorporation on number of kernels per row and 1000 seeds weight (g) of succeeding maize crop

Green manure crop (GMC)	Growth stage at incorporation (GSI)†			Un-incorporated	Mean*
	Mid-vegetative	Mid-flowering	Pod-setting		
Number of kernels/row					
Tef stubble	-	-	-	-	30.33b
Weed fallow	-	-	-	-	32.67ab
Cowpea	29.0	32.3	40.0	34.3	33.83ab
Black Dessie	32.7	30.7	30.3	30.0	30.93b
Awash Melka	33.7	28.0	37.0	30.3	32.25ab
Soybean	30.5	33.0	38.7	42.7	36.22a
Mean*	31.45b	31.00b	36.43a	34.33ab	
	GMC	GSI	GMC × GSI		
LSD (0.05)	4.46	4.41	NS		
1000 seeds weight (g)					
Tef stubble	-	-	-	-	281.67c
Weed fallow	-	-	-	-	292.67a-c
Cowpea	294.7	307.3	315.3	296.0	303.33a
Black Dessie	288.0	282.7	292.7	278.7	285.53bc
Awash Melka	289.4	289.0	296.0	298.7	295.78ab
Soybean	307.3	299.0	305.3	310.7	305.58a
Mean	294.85	294.50	302.33	296.00	
	GMC	GSI	GMC × GSI		
LSD (0.05)	14.10	NS	NS		

*Means within a row or a column followed by the same letter are not significantly different at P≤0.05 probability level.
†GMC = Green manure crop; GSI = Growth stage at incorporation; NS = Non-significant.

Table.8 Effects of incorporation stage of green manure crops on total dry matter (DM) and grain yield (t ha^{-1}) of the subsequent maize crop

Green manure crop (GMC)	Growth stage at incorporation (GSI)†			Un-incorporated	Mean*
	Mid-vegetative	Mid-flowering	Pod-setting		
Total DM (t ha^{-1})					
Tef stubble	-	-	-	-	4.815b
Weed fallow	-	-	-	-	5.74b
Cowpea	6.56	8.37	10.59	6.30	7.955a
Black Dessie	4.92	6.03	7.25	3.98	5.545b
Awash Melka	6.03	5.70	7.49	5.65	6.224b
Soybean	5.99	6.83	8.82	8.21	7.463a
Mean*	5.881b	6.539ab	8.574a	6.035b	
	GMC	GSI	GMC × GSI		
LSD (0.01)	NS	2.091	NS		
(0.05)	1.777	-	NS		
Total grain yield (t ha^{-1})					
Tef stubble	-	-	-	-	2.59c
Weed fallow	-	-	-	-	2.73bc
Cowpea	3.37	4.59	5.10	3.50	4.14a
Black Dessie	2.37	3.19	3.04	2.20	2.70bc
Awash Melka	3.09	3.42	3.62	2.54	3.17a-c
Soybean	3.40	3.05	4.60	4.75	3.95a
Mean*	3.055b	3.564ab	4.090a	3.249ab	
	GMC	GSI	GMC × GSI		
LSD (0.05)	0.99	0.98	NS		

*Means within a row or a column followed by the same letter are not significantly different at the specified probability level.

†DM = Dry matter; GMC = Green manure crop; GSI = Growth stage at incorporation; NS = Non-significant

Table.9 Partial budget with dominance and marginal analysis to establish the profitability of maize production after green manuring legume crops and growth stages at incorporation

Green manure crop	Partial budget with dominance†			
	GFB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Dominance
Tef stubble	906.50	328.65	577.85	Undominated
Weed fallow	955.50	383.25	572.25	Dominated
Awash Melka	1101.10	448.95	659.75	Undominated
Black Dessie	1168.10	460.05	708.05	Undominated
Cowpea	1449.0	478.95	970.05	Undominated
Soybean	1382.50	489.10	893.35	Dominated

Marginal rate of return (MRR%)					
	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Incremental cost	Incremental benefit	MRR (%)
Tef stubble	328.65	577.85	-	-	
Awash Melka	448.95	659.75	120.30	81.90	68.07
Black Dessie	460.05	708.05	11.10	48.30	435.13
Cowpea	478.95	970.05	18.90	262.00	1386.24

Residue management	Partial budget with dominance†			
	GFB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Dominance
Un incorporated	1136.60	350.65	785.95	Undominated
Mid-vegetative	1070.10	488.10	582.00	Dominated
Mid-flowering	1246.80	494.60	752.20	Dominated
Pod-setting	1295.80	502.25	793.55	Undominated

Marginal rate of return (MRR%)					
	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Incremental cost	Incremental benefit	MRR (%)
Un incorporated	350.65	785.95			
Pod-setting	502.25	793.55	151.60	7.60	5.01

†ETB = Ethiopian Birr; GFB = Gross field benefit; MRR = Marginal rate of return; NB = Net benefit; TVC = Total variable cost.

harvestable cobs by 252.94% per unit area over the control plot (maize after *tef*). Generally, the improvement of the soil conditions or enrichment with nutrients and organic matter due to soil-added materials might be responsible for better cob production under plots treated with legume GM.

The effect of incorporation stage of legume crops was also found to be significant ($P \leq 0.01$) on the number of maize cobs m^{-2} (Table 6). In this regard, a linear increase in number of maize cobs was recorded with the maturity of the soil-added plant materials, wherein delayed incorporation to pod-setting stage yielded 31.6% more cobs than incorporated at mid-vegetative stage. This is attributable to more leguminous phytomass added into the soil during later stage of incorporation.

The difference among GM legume types, weed fallow and *tef* stubble with respect to the length of maize cobs was found to be non-significant ($P > 0.05$). Incorporation stage treatment effect on the length of maize cobs was, however, found significant ($P \leq 0.05$), where an increasing trend was recorded with delayed incorporation of the GM legume crops (Table 6). The mean of rotation plots also recorded longer cobs (14.23) than those grown on legume incorporated at mid-vegetative stage (13.83). Generally, on average larger cobs were produced under legume treated and fallowed soils than maize following cereal (*tef*), and at delayed incorporation of GM legume crops than early stage of growth.

The dry cob weight was found to vary significantly among GM species, whereby maize grown after soybean recorded the highest weight (191.9 g) and maize on *tef* stubble the lowest (128.0) (Table 6). The mean of soybean treated plots recorded 49.92% heavier cobs than the control (*tef* stubble). Jabłońska-Ceglarek and Rosa (2005) also observed that maize cultivated after GM of a mixture of vetch with oat produced significantly heavier cobs than maize grown on the control without green manure.

Thousand seeds weight of maize crop, in the present study, also showed a significant variation due to the practice preceding maize, whereby the mean weight of 1000 seeds of maize grown on soybean treated plots recorded 23.91 g more weight than maize grown after *tef* (Table 7). The higher yield attribute values of the maize crop recorded with delayed incorporation of the green manures in this study, is generally attributable to the differential leguminous phytomass input and subsequent improvement of soil organic matter level.

Effect on total dry matter and grain yields of maize

Dry matter yield of maize crop succeeding *tef*, weed fallow and GM legume crops, in the present study, showed a significant variation ($P \leq 0.05$), where maize DM succeeding cowpea GM produced the highest means amount compared to the rest. The lowest amount was, however, produced in plot where maize followed *tef* (Table 8). The effect of the legume incorporation stage on DM yield of the maize crop was also found highly significant. In this regard, biomass production of maize crop increased with delayed incorporation of legume crops, where the highest mean was recorded in plots treated at pod-setting stage of growth, attributable to the amount of leguminous material added into the soil.

Total grain yield of maize crop in the present study, was significantly affected ($P \leq 0.05$) by the preceding practices, where maize crop after cowpea GM gave the highest mean yield; whereas maize after the cereal (*tef*) yielded the least (Table 8). Similar observations were also made by Sakala *et al*. (2004) and Miller *et al*. (2011), whereby grain yields of cereals following green manures were significantly higher than from plot where cereals were being grown continuously. The DM and grain yields of maize crop, in the present study were found to be determined by the organic C content of the soil, might be due to the differential DM inputs from legume green manures. This is corroborated by highly significant positive relationships observed in the present study, between the organic C content and DM (r = 0.88**) and grain (r = 0.80**) yields of maize crop in the subsequent season (Figure 3).

Significant ($P \leq 0.05$) effect of growth stage at incorporation of GM legumes legume was also observed on grain yield of the subsequent maize crop, wherein an increasing trend of maize grain yield was recorded with delay in incorporation of legume green manures. According to this result, by delaying incorporation of legume crops to the pod-setting stage of growth, grain yield could be increased by about 33.88% compared to mid-vegetative state of incorporation (Table 8).

Similar observations were made by various workers, whereby increased yield of subsequent maize crop was observed by delaying kill date of various legume and non-legume cover crops, which they attributed to greater improvement of soil conditions by the late kill (Sainju and Singh, 2001; Lahti and Kuikman, 2003; Clark *et al*., 2007). In difference with this finding, Sakala *et al*. (2004) reported that no significant maize yield differences were observed when maize followed early or late incorporated *Mucuna pruriens*, *Crotalaria juncea* and *Lablab purpureus* green manures.

Delaying incorporation (particularly cowpea) to pod-setting stage of growth could, therefore, be considered as effective strategy, as it was found to be superior in production of leguminous phytomass that largely contributed to higher yields of the subsequent crop. This proved the observations of Kelling *et al*. (2001) who stated that legumes to be considered as effective green manures; they must supply sufficient biomass and must release the legume N to meet the demand of the succeeding crops.

In this study, the means of maize DM and grain yields from plots where legumes were grown for grain (unincorporated) were found to be higher than that of GM at mid-vegetative stage or maize after *tef* (Table 8). This showed that growing legumes for grain in rotation are more efficient in cycling nutrients than terminating early at vegetative stage as green manure or cereal after cereal. Pedersen and Lauer (2003) also reported that soybean annually rotated with maize produced 17% more grain yield than continuous maize. Sauerborn *et al*. (2000) also recorded the lowest grain and straw yields of maize after another cereal, sorghum when grown as a preceding crop. Within the context of soil functions and cropping system performance results from the study of Liebig *et al*. (2002) also indicates that legume cereal sequence enhanced nutrient cycling efficiency.

Economic variability of green manure legumes and incorporation stages

The result of the partial budget and the data used in the development of this are given in Table 9. Ranking of treatments in order of increasing total variable cost (TVC) revealed that *tef* stubble costs less than either legume GM or fallow land. It is clear that *tef* stubble has considerably reduced costs of labor and oxen-power for seed bed preparation compared to others. The highest gross field benefit (GFB) and net benefit (NB) were, however, obtained with cowpea GM (1449 and 970.05 ETB/ha, respectively) (Table 9). Similarly, in West Africa, mucuna biomass incorporation significantly increased the subsequent rice yields compared to weed fallow and mucuna biomass removal (Buckles *et al.*, 1998; Carsky *et al.*, 1998).

Among the residue management treatments, unincorporated legumes (grown for grain) costs the least and incorporation of legume crops at their pod-setting stage of growth gave the highest GFB and NB (Table 9). The dominance analysis, in the present study, indicated that among the legume varieties and control treatments, soybean and weed fallow were those which cost more but granted lower NB than the treatments costing lower to them (dominated). Whereas unincorporated and incorporation at pod-setting stage treatments were the undominated among the residue management strategies (Table 9). The analysis of MRR, on the other hand, revealed that the return per unit production cost was highest from cowpea (% MRA = 1386.24) compared to others and pod-setting stage of legumes termination for GM gave 5 Birr return for each invested Birr during the production (Table 9). This showed that cowpea and legume kill time at pod-setting were the most efficient in reducing production costs compared to the respective treatments of the two variables studied.

In comparison with cereal after cereal and weed fallow, legume GM was found to be better in improving the soil organic C content. The effects of green manure crops and residue management on the soil were associated primarily with the quantity of the biomass produced, where plots treated with greater phytomass had higher soil organic C levels. Following the GM, the yield and yield components of the succeeding maize crop were significantly affected by the legume species and growth stage at incorporation. The total DM and grain yields of the succeeding maize crop were also significantly affected by these treatments, where the highest harvests being recorded by cowpea species and pod-setting stage of incorporation, attributed to the amount of soil-added biomass and the corresponding improvement of soil organic C content. Compared to late incorporation, legume tissues incorporated early at mid-vegetative stage did not contribute much to the build-up of soil organic matter content and the grain yield of the subsequent crop.

Generally, delaying incorporation of the green manures that increased the biomass yield of legume crops also augmented the DM and grain yield of the subsequent maize crop, attributable to improvement of soil-plant environment, which is corroborated by highly significant positive relationships observed between soil organic C content and maize DM yield (r = 0.88**) and grain yield (r = 0.80**). This highlights that the overall contribution of leguminous GM crops to the yield of the subsequent crop generally depended upon the amount of biomass input, which in turn was determined by the species (vigor) and duration of growth cycle (kill time). The economic evaluation, on the other hand, revealed that the highest net benefits were obtained from green manuring of cowpea and pod-setting stage of growth compared to cereal after cereal and early termination, respectively. Hence, it is likely to conclude that introduction of legume green manures in cropping systems would be ecologically friendly and economically justifiable.

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