Journal of Resources Development and Management www.iiste.org
ISSN 2422-8397 An International Peer-reviewed Journal
Vol.23, 2016

Review on the Role of Integrated Soil Fertility Management in Improving Maize Production in Ethiopia

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Abstract
In Ethiopia, bulk of maize has been produced in humid and mid-altitude agro-ecologies and cultivated continuously on the same piece of land and resulting nutrient depleted soils. To avert low soil fertility problems in the country, commercial fertilizers have been relied to boost the productivity of maize in continuous production system. However, escalating costs of inorganic fertilizers may not encourage the smallholder farmers to use the full dose of fertilizers recommended for their crops. It is thus, to look for another alternative that reduce the cost of production while increasing the productivity of soils. Integrated soil fertility management has been proven to harmonize the current need of smallholder farmers and to produce maize using low input fertilizers from organic sources such as farmyard manure, green manures, compost and also crop rotations. Therefore, several research attempts have been made to optimize the integrated uses of inorganic and organic fertilizers at different locations. At Bako maize rotated with nug and at Jimma maize following soybean reduced the recommended fertilizer rates by 50%. Yearly application of 4 ton FYM ha^{-1} with 46/10 kg NP ha^{-1}gave maize yield comparable to 110/20 kg NP ha^{-1} and use of compost also had similar trends at Bako. Uses of legumes such as mucuna and Dolichos lablab at Bako and crotalaria, sesbania and mucuna at Jimma as short fallows and green manures enhanced soil fertility and confirmed to replace either partially or fully the N-fertilizer requirement of maize from external sources. Research reports on integration of crop residues with NP fertilizers at Haramaya and coffee by products integrated with N-fertilizer at Areka could enhance soil fertility and made maize production trends sustainable in Ethiopia. The literatures insights on integrated soil fertility management options for maize production in Ethiopia were reviewed in this paper.
Keywords: Soil Fertility, Organic Fertilizers, Inorganic Fertilizers, Maize, Yield

1. INTRODUCTION

Maize (*Zea mays* L.) is one of the principal food crops in Ethiopia. It is also the most important cereal crop in terms of area coverage, production, and economic importance in Ethiopia (Legesse *et al*., 2011). According to CSA (2010) maize occupied 2.1 million hectares (ha) of land with estimated average yield of 2.9 tons (t) ha^{-1}. This is far below the world average 5.1 t ha^{-1} (FAO, 2008). One of the major constraints affecting maize production and productivity is declining soil fertility and inadequate crop management practices (CIMMYT, 1999).

In Ethiopia, bulk of maize has been grown in humid agro-ecology within the altitudinal ranges of 1500 to 1800 meters above sea level that contributes to 80% of the national maize production (Kebede *et al*., 1993). In this agro-ecology, pressure on land to put under cultivation has been increased in time series with raising population and following by gradual reductions of fallow periods (McCann, 1995). In addition, maize has been cultivated continuously on the same piece of land and most of these areas are characterized by cereal-livestock farming systems where free grazing animals remove more of crop residues than are returned in to soils for nutrient recycling, and aggravate soil erosion and high loss of nutrients (FAO, 2000; Thorne *et al*., 2002). It has also been observed that crop rotations are very rarely practiced and legumes are absent in the system (Tesfa *et al.,* 2009). However, commercial fertilizers have been relied to boost the productivity of maize in continuous cropping systems. Eventually, escalating costs of inorganic fertilizers may not encourage the purchasing potential of resource poor farmers. In this trend most farmers use to apply sub-optimal doses of fertilizers to their crops.

Therefore, maize production in Ethiopia has been facing critical constraints of gradual soil fertility declining due to unwise uses of fertilizers, including organic amendments. On the other hand, research efforts made on different sources of organic fertilizers show bright scenario for maize production in smallholder fields (Tolera *et al.,* 2009; Tasfa *et al.,* 2009; Negassa *et al.,* 2004; Tolessa *et al.,* 1999a). These authors reported that legume rotations, integrated use of mineral and organic fertilizers, green manure legumes resulted in enhanced soil fertility and promised smallholder farmers to produce maize at low cost. In addition they help to increase organic matter content of the soil which in turn improves the physic-chemical characteristics of the soil notably, increase water holding capacity of the soil. They also improve the nutrient retention property of the soil serve as reservoir of the micronutrients and reduce leaching losses of nutrients (Vanlauwe *et al.,* 2005; Ravishankar *et al.,* 2002). Besides, they increase the fertilizer use efficiency of crops (Lindqvist, 2005).

Modern nutrient management strategy has shifted its focus towards the concept of sustainability and eco-friendliness. Integrated use of various soil fertility amendment inputs aims at alleviating the limiting nutrients problem and improves their availability through interactions with the mineral soil and reducing the P sorption capacity of the soil (Palm and Sanchwez, 1997). The integrated nutrient management paradigm acknowledges the need for both organic and inorganic mineral inputs to sustain soil health and crop production due to positive interactions and complementarities between them (Sanchew and Jam, 2000). Therefore, it is very essential to review different research findings in the country on integrated soil fertility management for maize production. Thus, the objective of this paper is to review on integrated soil fertility management on the productivity and yield of maize in Ethiopia.

2. Literature review

2.1 Uses of oil crops and grain legumes for rotation in maize system

A study conducted at Bako using nug as proceeding crop indicted that maize grain yields were significantly increased in rotation with this crop compared to the continuous cropped maize (Table 1). This result clearly demonstrated the residual benefits of crop rotation with reduced NP fertilizer amendments and enhanced maize grain yield. Also the integrated use of precursor crops with low rate of NP and farmyard manure gave comparable maize yield to a plot received recommended fertilizer rate (110/20 kg NP ha^{-1}). Production of maize following nug as a precursor crop by integrating with 46/5 kg ha^{-1} NP and 8t FYM ha^{-1} could be affordable for smallholder farmers in Bako areas.

Table 1. Effects of precursor crops, NP and FYM fertilizer rate on grain yield of maize at Bako

Precursor crop	N/P kg ha^{-1} + FYM t ha^{-1}	Grain yield (kg ha-1)		
		2002	2003	Mean
Nug	23/5 + 4	7815	6833	7324
Nug	23/5 + 8	7968	6726	7347
Nug	23/10 + 4	7723	6675	7199
Nug	23/10 + 8	8383	8040	8211
Nug	46/5 + 4	8138	7440	7789
Nug	46/5 + 8	9226	8705	8965
Nug	46/10 + 4	6585	7310	6947
Nug	46/10 + 8	8859	8046	8453
Continuous Maize	110/20 + 0	9639	7467	8553
LSD <0.05		Ns	1142	1069

Source: Tolera et al. (2005c)

Another trial on rotation of common bean in sole and intercropping systems with maize at Bako demonstrated that maize planted following sole planted common bean gave higher mean grain yield and found economically profitable as compared to maize produced following intercropped haricot bean or continuous maize (Table 2). Therefore, maize production following sole common bean with recommended fertilizer could be another alternative for sustainable maize production in Bako areas. A crop rotation study on maize rotated with soybean in four districts of Jimma zone showed 26-46% increments of maize grain yield whenever rotated on previous soybean field (Table 3). It was also further notified that soybean contributed 46kg urea-N ha^{-1} to succeeding maize and thus, it could offset the cost of 46 kg urea-N ha^{-1} for smallholder farmers (Table 4).

Table 2. Effects of common bean rotations and N/P fertilizer rate on grain yield of succeeded maize

Treatment		Grain yield (kg ha^{-1})		
Crops (2004)	Maize with N/P_2O_5 kg ha^{-1}	2005	2006	Mean
M/BB	M-59/23	5950	4254	5102
M/BB	M-89/35	6484	3897	5191
M/BB	M-110/46	6935	5777	6356
BB	M-59/23	8691	5872	7281
BB	M-89/35	8571	5841	7206
BB	M -110/46	9550	6052	7801
M/CB	M- 59/23	5055	4429	4742
M/CB	M- 89/35	6278	5508	5893
M/CB	M- 110/46	7797	5686	6742
CB	M- 59/23	8457	4517	6487
CB	M- 89/35	9240	5733	7486
CB	M -110/46	10148	6066	8107
M	M -110/46	7314	6123	6718
LSD <0.05		2374	1879	1484

Source: Anon. (2004-2007), M/BB = maize/bush bean intercropping, BB = sole bush bean, M/CB = maize/climbing bean intercropping, CB = sole climbing bean, M = sole maize,

Table 3. Soybean rotation effects on subsequent maize grain yield

Crops in Rotation* + N-Levels	Seasons		Rotation Mean	% increase
	2003	2004		
Maize grain yield in kg ha^{-1}				
CMZF + 18 kg N ha^{-1}	3013	4693	3853c	-
CMZF + 64 kg N ha^{-1}	4077	5628	4852b	26
PSYF + 18 kg N ha^{-1}	4417	5298	4857b	26
PSYF + 64 kg N ha^{-1}	5109	6185	5647a	46
Season-mean	4154b	5451a		

Source: Tesfa et al. (2009), *PSYF (previous soybean field) and CMZF (Continuous maize field)

Table 4. Economic benefits of soybean rotation to subsequent maize

Crops in Rotation* + N-Levels	Maize grain yield in kg ha^{-1}	Gross Return **ETB ha^{-1}	Net benefit ETB ha^{-1}	VCR
CMZF + 18 kg N ha^{-1}	3853	3467.70	3162.70	10
CMZF + 64 kg N ha^{-1}	4852	4366.80	3789.89	7
PSYF + 18 kg N ha^{-1}	4857	4371.30	4066.30	13
PSYF + 64 kg N ha^{-1}	5647	5082.30	4505.30	8

Source: Tesfa et al. (2009), PSYF (previous soybean field) and CMZF (Continuous maize field,
**ETB 8.67 = US$ 1.00 and MRRI (marginal rate of return on investment)

2.2 Integrated management of NP with farmyard manure and biogas effluent

As long term research strategy on locally available sources of organic fertilizers was designed on a continuous basis for replenishing the degraded physic-chemical properties of soils to make sustainable maize production in Bako areas and similar locations. Accordingly, a study carried out on integrated uses of NP and FYM at five on farms sites indicated that integrated application are better than application either NP or FYM alone (Table 5). While previous studies at the same location revealed that FYM has to be applied every three years at the rate of 16 t ha^{-1} supplemented by NP fertilizer annually at the rate of 20-46 N-P_2O_5 kg ha^{-1} (Table 6) for sustainable maize production around Bako and similar areas (Tolessa *et al.,* 1999a).

Nutrient requirement of maize intercropped with common bean (climbing type) was evaluated by integrating farmyard manure and NP fertilizer rates at Bako. Soil samples collected after application of FYM were analyzed and results showed that application of FYM improved soil pH and SOC contents (Table 7). Subsequently, the combined mean yield results of both component crops justified that nitrogen and farmyard manure significantly affected grain yield of climbing bean (Table 8). Lucky enough, maize growth was not affected by intercropping system. In addition, higher LER was obtained that intercropping gave up to 42% land use advantage over separate planting of each crop (Table 8). Thus, application of 46/10 kg NP ha^{-1} with 4t FYM ha^{-1} produced better gain yields of both intercropped maize and climbing bean and these rates are recommended for sustainable production of component crops in Bako and similar areas.

At Bako, a trial was executed on uses of biogas effluent as organic fertilizer with integration of NP rates. The biogas effluent brought significant change in chemical composition of the soil in particular, soil organic carbon was fairly increased (Table 9). After application the integration of both fertilizers was observed to produce significantly higher grain yield (Table 10). Although 12 t ha^{-1} biogas effluents alone gave higher yields that were comparable to other treatments, biogas effluent applied at 8t ha^{-1} with 55/10 kg NP ha^{-1} was selected as the best alternative fertilizer combination and thus, recommended for maize production in Bako areas.

Table 5. Effects of NP and FYM on maize yield at five sites around Bako, 1997

N/P kg ha^{-1} + FYM t ha^{-1}	BRC	Walda	Shoboka	Harato	Laga Kalla	Mean
	Grain yield t ha^{-1}					
0/0 + 0	0.90	4.68	4.44	5.79	1.86	3.53
0/0 + 4	3.61	6.68	6.43	7.72	4.37	5.76
0/0 + 8	4.87	6.50	6.52	5.74	4.41	5.61
0/0 + 12	5.05	6.71	6.95	6.78	4.17	5.93
20/20 + 0	3.79	6.70	6.88	6.20	4.75	5.66
20/20 + 4	4.69	7.44	7.82	6.96	3.27	6.04
20/20 + 8	6.50	6.88	7.44	8.94	4.35	6.82
20/20 + 12	6.50	5.76	6.52	7.28	4.75	6.16
40/25 + 0	4.33	6.12	6.70	9.06	4.46	6.13
40/25 + 4	5.05	5.71	8.00	6.78	4.66	6.04
40/25 + 8	5.96	7.98	7.64	7.57	5.67	6.96
40/25 + 12	5.96	6.88	7.44	6.00	5.44	6.34
60/30 + 0	4.51	6.52	6.52	7.68	5.04	6.06
60/30 + 4	5.77	7.05	7.47	7.68	4.67	6.53
60/30 + 8	7.40	6.52	6.88	7.34	5.85	6.80
60/30 + 12	6.78	7.80	7.64	9.58	6.61	7.68
LSD <0.05	1.24	1.86	Ns	2.02	1.32	0.72

Source: Wakene et al. (2004a) BRC= Bako Research Center, NS= non-significant difference at 5 % probability level.

Table. 6. Effects of farmyard manure and inorganic fertilizers on of maize at Bako, 1992-1995.

FYM-N-P_2O_5 t-kg ha^{-1}	1992	1993	1994	1995	Mean
	Grain yield kg ha^{-1}				
0-0-0	2830	3301	2126	2299	2639
0-10-23	3122	3795	3583	2933	3382
0-20-46	3355	4319	3982	3365	3755
8-0-0	3881	3800	3267	2920	3467
8-10-23	2609	4063	4069	3569	3577
8-20-46	2651	4847	5607	4421	4381
16-0-0	3125	4580	4035	3501	3810
16-10-23	3535	5122	5616	4451	4681
16-20-46	3150	5671	5865	4999	4921
24-0-0	3245	4397	4705	4095	4106
24-10-23	2807	5333	5437	4851	4607
24-20-46	3573	5450	6105	5535	5166
0-75-75	5439	5463	6090	5587	5645
LSD <0.05	639	568	556	594	493

Source : Tolessa, (1999a)

Table 7. Chemical analysis of soils sampled after FYM application in maize-climbing bean intercropping system

N/ P Kg/ha + FYM* t/ha + MZ* + CB*	Chemical nutrients					
	PH: H_2O	TN (%)	OC (%)	C/N	Av. P (ppm)	Av. K (ppm)
46/10 kg N/ P/ha +4 t/ha FYM + MZ + CB	5.6	0.12	1.995	17	4.40	108
46/10 kg N/ P/ha +8 t/ha FYM + MZ + CB	5.7	0.11	1.195	11	6.46	108
46/20 kg N/ P/ha + 4 t/ha FYM + MZ + CB	5.6	0.12	2.055	17	4.36	127
46/20 kg N/ P/ha +8 t/ha FYM + MZ + CB	5.6	0.169	2.035	12	5.64	83
69/10 kg N/ P/ha +4 t/ha FYM + MZ + CB	5.5	0.113	1.915	17	6.00	82
69/10 kg N/ P/ha +8 t/ha FYM + MZ + CB	5.8	0.165	2.035	12	8.18	165
69/20 kg N/ P/ha +4 t/ha FYM + MZ + CB	5.6	0.143	2.113	15	7.18	175
69/20 kg N/ P/ha +8 t/ha FYM + MZ + CB	5.6	0.155	1.895	12	4.30	41
110/20 kg N/ P/ha + 0 t/ha FYM + MZ	5.4	0.18	1.835	10	3.98	105
110/20 kg N/ P/ha + 0 t/ha FYM + MZ + CB	5.5	0.15	1.815	12	3.16	110
16 t FYM /ha + sole maize	5.8	0.163	1.953	12	8.92	76
16 t FYM /ha + MZ + CB	5.7	0.253	1.915	8	7.26	124
18/20 kg N/ P/ha sole CB	5.5	0.15	1.855	12	4.76	110
Before sowing	5.2	0.168	2.454	15	21.0	41
FYM		1.213	12.688	10	214.6	2850

Source: Tolera et al. (2005b), FYM* (farmyard manure) MZ* (maize), CB* (Common bean),

Table 8. Interaction of NP and FYM on grain yield and LER of maize-climbing bean intercropping system

N/ P kg/ha + FYM* t/ha + MZ* + CB*	Grain yield (kg/ha)		LER
	Maize	Climbing bean	
46/10 kg N/ P/ha +4 t/ha FYM + MZ + CB	5700	1309	1.34
46/10 kg N/ P/ha +8 t/ha FYM + MZ + CB	5950	1220	1.32
46/20 kg N/ P/ha + 4 t/ha FYM + MZ + CB	4878	1274	1.15
46/20 kg N/ P/ha +8 t/ha FYM + MZ + CB	5797	1398	1.38
69/10 kg N/ P/ha +4 t/ FYM + MZ + CB	6116	1310	1.40
69/10 kg N/ P/ha +8 t/ha FYM + MZ + CB	5906	1389	1.41
69/20 kg N/ P/ha +4 t/ha FYM + MZ + CB	6102	1306	1.39
69/20 kg N/ P/ha +8 t/ha FYM + MZ + CB	5607	1491	1.42
110/20 kg N/ P/ha + 0 t/ha FYM sole MZ	6983	-	1.00
110/20 kg N/ P/ha + 0 t/ha FYM + MZ + CB	5658	1124	1.33
16 t FYM /ha + MZ + CB	4754	1463	1.28
16 t FYM /ha + sole MZ	6966	-	0.76
8/20 kg N/ P/ha sole CB	-	2276	1.00
LSD <0.05	914.3	194.5	0.19

Source: Tolera et al. (2005b), FYM* (farmyard manure) MZ* (maize), CB* (Common bean),

Table 9. Effects of biogas slurry and NP rates on soil chemical and physical properties in at mid growing period of maize

BE ha^{-1} t ha^{-1} and NP rates kg ha^{-1}	pH: H_2O	Total N (%)	O.C (%)	C: N	Avail.P (ppm)	Na	K	Ca	Mg
						Meq/100 g soil			
4 t BE ha^{-1} + 50 % RR NP kg ha^{-1}	5.9	0.15	1.815	12	5.98	0.24	2.01	4.44	1.32
4 t BE ha^{-1} + 75 % RR NP kg ha^{-1}	5.8	0.15	1.815	12	6.80	0.27	2.03	4.64	1.40
4 t BE ha^{-1} + 100 RR NP kg ha^{-1}	5.8	0.15	1.835	12	6.64	0.27	2.48	4.19	1.32
8 t BE ha^{-1} + 50 % RR NP kg ha^{-1}	5.7	0.15	1.815	12	6.22	0.10	1.84	3.89	1.15
8 t BE ha^{-1} + 75 % RR NP kg ha^{-1}	5.8	0.14	1.815	12	8.22	0.16	2.52	4.29	1.40
8 t BE ha^{-1} + 100 % RR NPkg ha^{-1}	5.8	0.15	1.815	12	7.76	0.30	2.09	4.29	1.24
12 t BE ha^{-1} + 50 % RR NPkg ha^{-1}	5.8	0.14	1.776	12	6.80	0.22	1.94	4.59	1.40
12 t BE ha^{-1} 75 % RR NP kgha^{-1}	5.8	0.16	1.915	12	8.80	0.24	2.39	4.74	1.40
12t BE ha^{-1} +100 % RR NPkg ha^{-1}	5.8	0.143	1.915	13	7.44	0.24	2.06	4.49	1.56
12 t BE ha^{-1}	6.2	0.15	1.935	13	10.74	0.20	2.62	5.59	1.89
RR NP kg ha^{-1} (110/20)	5.9	0.15	1.815	12	6.96	0.14	2.04	4.59	1.24
16 t BE ha^{-1}	6.0	0.13	1.815	14	5.74	0.12	0.25	5.14	1.48
Preplanting	5.2	0.17	2.45	15	21.0		41		
Biogas effluent		1.26	14.20	11	210		2550		

Source: Tolera et al. (2005a), BE (Biogas effluent), RRNP (recommended rate of nitrogen and phoshorus)

Table 10. Combined effects of biogas effluent and NP fertilizer rates on grain yield of maize at Bako,

BE ha^{-1} t ha^{-1} and NP rates kg ha^{-1}	Grain yield (kg/ha)			
	2001	2002	2003	Mean
4 t BE ha^{-1} + 50 % RR NP kg ha-1	8998	6741	2668	6135
4 t BE ha^{-1} + 75 % RR NP kg ha-1	9609	6623	3154	6462
4 t BE ha^{-1} + 100 RR NP kg ha-1	9568	7556	2812	6645
8 t BE ha^{-1} + 50 % RR NP kg ha-1	9837	7846	4357	7346
8 t BE ha^{-1} + 75 % RR NP kg ha-1	9061	8204	3575	6947
8 t BE ha^{-1} + 100 % RR NP kg ha-1	9662	7628	3698	6996
12 t BE ha^{-1} + 50 % RR NP kg ha-1	9549	7821	3326	6899
12 t BE ha^{-1} + 75 % RR NP kg ha-1	9389	7537	3709	6878
12 t BE ha^{-1} + 100 % RRNP kg ha-1	9923	9395	4187	7835
12 t BE ha^{-1}	9216	7840	5131	7396
RR NP kg ha^{-1} (110/20)	9894	6265	2051	6070
16 t BE ha^{-1}	8332	9023	4664	7340
LSD<0.05	1126	2106	1503	NS

Tolera et al. (2005a), BE (Biogas effluent), RRNP (recommended rate of nitrogen and phoshorus)

2.3 Integrated use of compost with NP fertilizer

A field trial on integrated use of compost and mineral fertilizer was conducted on farmers' field around Bako Research Center in seasons 2000 and 2001. Treatments used are given in table 12. The compost prepared for the trial was analyzed before application and the results of its chemical composition revealed higher amount of macronutrients and significant quantities of basic cations and micronutrients (Table 11). The combined analysis of maize grain yield across location and season showed significant differences ($P \leq 0.05$) among the treatments. The recommended rate of NP (110/20 kg N/P ha^{-1}) gave the highest mean grain yield, though five tons ha^{-1} compost integrated with 25/11 kg N/P and 50/10 kg N/P ha^{-1}produced comparable average maize grain yield (Table 12). Likewise, the highest marginal rate of return of 213.2% and 135.8% was recorded from 55/10 kg of N/P + 5 tons ha^{-1} of compost and 25/11 kg of N/P + 5 tons ha^{-1}, respectively (Table 12). Therefore, use of five tons ha^{-1} of compost with 55/10 kg of N/P ha^{-1} is found economical for maize production in western regions.

Table 11. Elemental composition of the compost used in the experiments (Bray-II method)

A) Nutrient Element Composition of Compost										
TN (%)		Available nutrients (mg kg^{-1})					Exchangeable bases (cmol$_c$kg^{-1})			
	Total P	Bray II P	Fe	Mn	Zn	Cu	Na	K	Ca	Mg
3.42	8220.0	92.0	25.6	52.2	16.8	2.5	0.5	5.8	20.7	13.8
B) Quantity of nutrients (kg) in the 5 t compost ha^{-1}										
TN (%)	Total P	Bray II P	Fe	Mn	Zn	Cu	Na	K	Ca	Mg
171.00	41.10	0.46	0.13	0.26	0.08	0.01	0.55	11.42	20.20	8.44

Source: Wakene et. al. (2004b), TN = Total Nitrogen, Bray II P = Available P extracted with

Table 12. Effect of integrated use of compost and low doses of NP fertilizers on maize grain yield

NP kgha-1 + compost th-^{1}	Bako	Kejo	Anno
0/0 + 0	4025b	3670c	3740d
0/0 + 5 compost	5450ab	5340b	4730c
25/11 N/P + 5 compost	5840ab	6600a	5680b
55/10 N/P + 5 compost	6990a	6120a	6510a
110/20 N/P + 0	6490a	7350a	6850a

Source: Wakene et al. (2004b), Means within a column followed by the same letter(s) are not significantly different at P<0.05

2.4 Integrated management of green manure legumes with FYM and NP fertilizer

At Bako integrated use of improved fallow of mucuna [*Mucuna pruriens* (L) DC] with NP fertilizers enhanced soil chemical properties mainly soil pH, basic cations and reduced exchangeable acidity and increased uptake of nitrogen, phosphorus, and potassium in maize (Negassa *et al.*, 2007). The integrated use of these organic sources with inorganic fertilizers significantly improved maize grain yield over the control and recommended rate of inorganic fertilizers (Table 13). During three cropping seasons (2001 to 2003) the use of short fallow of mucuna alone increased maize grain yield by 11% over the control. Therefore, short fallowing of mucuna along with FYM or with low dose of NP fertilizers may be used as low cost intermediate technology for enhancing soil fertility and increased maize yield and also grantee sustainable maize production in western Ethiopia.

Another trial on use of *Dolichos lab lab* as green manure without integration of other fertilizer sources increased maize grain yield by two to three tons over the control on less depleted sites, such as Bako and Shoboka. Unlikely, it did not because significant yield change on highly depleted soils of Shoboka (Table 14). Therefore, using only *Dolichos lab lab* green manure can replace the recommended N fertilizers on moderately fertile soils, like Bako and Shoboka. However, for low soil fertility status like Walda, the green manure of the same legume should be supplemented with half of the recommended NP fertilizers for better maize production in the Western Ethiopia.

Table 13. Effects of integrated management of mucuna fallow with NP fertilizer on plant height and maize grain yield at Bako

Treatment	Plant height (cm)				Grain yield (t ha^{-1})			
	2001	2002	2003	Mean	2001	2002	2003	mean
Control	250	277	201	242	2.29	2.72	1.72	2.24
IF	295	312	248	285	4.00	4.31	5.92	4.74
IF +55/10 NP	347	304	269	311	7.89	4.01	5.84	5.91
IF +37/7 NP	339	319	248	297	7.66	3.81	5.87	5.78
IF+ 4 t ha^{-1} FYM	340	317	274	312	7.42	4.91	6.39	6.25
IF+ 2.7 t ha^{-1} FYM	341	318	270	309	6.31	4.25	7.32	6.06
110/20 kg h^{-1} NP	336	318	251	301	5.52	3.25	4.45	4.41
LSD <0.05	39.25	Ns	34.76	18.86	1.37	NS	1.81	0.85

Source: Wakene et al. (2007), IF= improved fallow with mucuna green manure,

Table 14. Effects of integrated use *Dalichos lablab* as green manure with NP fertilizer on maize grain yield (t/ha) on farmers field at different locations.

Treatments	Locations			Mean
	Bako	Walda	Shoboka	
No input	3.12	2.38	3.12	2.87
Green manure alone	5.20	2.70	6.33	4.74
Recommended NP	5.12	5.55	6.48	5.72
Green manure + ½ RRNP	5.20	4.60	5.60	5.13
Green manure + $_{1/3}$ RRNP	7.33	3.49	6.09	4.39
Green manure + RRNP	3.92	4.36	4.88	5.64
LSD <0.05	1.13	1.40	1.70	

Source: Anon (1999-2000), RRNP (Recommended 110/46 kg N/ P_2O_5 ha^{-1})

2.5 Minimum legume biomass and dry FYM determination for soil incorporation

Sesbania biomass and dried FYM with total N contents of 2.25% and 1.25% respectively were incorporate into soil at rates of 0, 5 and 10 t ha^{-1} a month before sowing of maize on research field of Jimma in seasons 1999 and 2000. During both years maize exhibited very attractive performance on plots that received the highest rate of sesbania and farmyard manure. Subsequently, at the same rate both gave significantly higher mean grain yield of 7.10 t ha^{-1} (Table 15). Therefore, application of sesbania biomass and dry FYM greater than 5 tha^{-1} gave comparable or greater maize yield to 69 kg N ha^{-1} from urea fertilizer. The grain yield gains due to N from organic sources were 50% and 40% as compared to the control and N received plots, respectively (Table 15). Five ton per hectare can definitely substitute the N-requirement of maize and determined to be a minimum dry weight to incorporate to soil for legumes and well managed FYM of total N-contents of greater than 2.5% and 1.25% respectively. Therefore, these should be advised for low cost and sustainable maize production in areas similar to Jimma.

Table 15. Minimum total dry biomass of a legume and FYM required for enhanced maize production

Available Inputs	Cropping seasons		Mean	% increase
	1999	2000		
5 t ha^{-1} sesbania	6.41	6.28	6.34ab	46
10 t ha^{-1}sesbanina	7.19	6.96	7.08a	63
5 t ha^{-1}farmyard manure	5.82	6.04	5.93bc	36
10 t ha^{-1} farmyard manure	6.83	7.53	7.18a	65
69 kg ha^{-1} N	5.52	4.45	5.04cd	16
0 kg ha^{-1}N	4.59	4.10	4.34d	-
Mean	6.06	5.91		

Source: Tesfa et al. (2004), Figures followed by the same letter are not significantly different at p<0.01

2.5.1 Screening legumes for short fallows and green manuring

Nine legume types from grain-legumes forage and fodder groups were evaluated for adaptation and potentials to accumulate nitrogen in their biomass at Jimma in season 1998 and 1999. Based on higher biomass production and N-accumulation, *Mucuna pruriens* and *Crotalaria ochralueca* from forage legumes, *Sesbania sesban* from fodder legumes were selected for further use as green manuring legumes for enhancement of soil fertility (Table 16). Soybean from grain legumes was selected for its high potential of N-fixation and inclusion in maize based farming system for crop rotation (Tesfa *et al*., 2009). Subsequent research efforts showed that from maize planted on previous sole green manure legume fields grain yield increases of 30-40% were obtained over plots received optimum N-fertilizer from external sources (Table 18). This implied that green manure of sole legumes had potentials to substitute more than 70 kg urea-N ha^{-1} (Table 17). On the other hand, from maize planted on previous plots of intercropped legumes with integration of one-half N from recommended rate showed yield increases of 10-20% over continuous maize plots that received the same N-rate (Table 18). This also implied that green manure of intercropped legumes could at least offset the cost of 46 kg N ha^{-1} from urea for smallholder farmers. Therefore, two options were set as how to utilize these legumes in maize base farming system. The option number one was for farmers having sufficient land, a sole legume could be grown and maize subsequently planted does not require additional N from external sources. The option number two was for those farmers who do not have sufficient land either *Mucuna pruriens* or *Crotalaria ochralueca* could be intercropped in between maize rows four weeks after maize emergence as a preceding crop and maize could be succeeded with application of one-half N recommended from external sources. Therefore, advice should be given for maize producers particularly; smallholders can sustain maize production in humid areas through inclusion of legumes for green manuring.

Table 16. Biomass yields and N-accumulated in shoots of potential legumes for green manure and yield advantages of subsequently planted maize: on station

Preceding legumes Compared to N-rate	Growth habits		Biomass yield returned to soil t ha^{-1}	Total-N in shoot returned to soil kg ha^{-1}	Grain yield of subsequent maize t ha^{-1}	% yield increase of subsequent maize
	Stand	Growth				
Canavalia ensiformis	Erect	Slow	7.85	263.76	9.51a	73
Crotalaria ochralueca	Erect	Slow	8.60	310.00	9.39a	64
Sesbania sesban	Erect	Fast	12.3	362.85	9.02ab	58
Cajanus cajan	Erect	Slow	12.51	275.22	8.67abc	52
Mucuna pruriens	Creeping	Fast	8.40	230.16	8.60abc	50
Dolichos lablab	Creeping	Fast	3.70	120.25	7.88bc	38
Calopogonium sp.	Creeping	Slow	4.40	119.68	7.67cd	34
Vecia desycarpa	Creeping	Fast	0.90	29.52	7.64cd	34
*Glycine max (*Var. SCS-1)	Erect	Fast	4.60	73.14	6.85de	20
69kg N ha^{-1}	-	-	-	-	5.72e	-

Source: Dennis et al. (2003)

Table 17. Biomass and grain yields of maize subsequently planted on previous fields of sole and intercropped legumes on station

Previous legume fields of sole and intercrops Compared to CSMz*	2001	2002	Mean biomass yield in t ha^{-1}	2001	2002	Mean grain yield in t ha^{-1}
	Maize Biomass yield in t ha^{-1}			Maize Grain yield in t ha^{-1}		
Mz + Muc ITEVS**	5.41	10.61	8.01de	1.60	4.03	2.82c
Mz + Muc IT FS	6.38	9.87	8.21de	2.36	3.76	3.06c
Mz + Cav ITEVS**	7.99	10.91	9.45cd	2.25	2.30	3.27c
Mz + Cav IT FS	5.99	9.64	7.81e	1.88	3.62	2.75c
Mz + Crt ITEVS**	7.50	10.53	9.01cd	2.15	4.34	3.25c
Mz + Crt IT FS	6.25	10.24	8.24de	1.96	4.13	3.04c
Sole Mucuna	9.52	14.88	12.20b	2.92	5.95	4.43b
Sole Canavalia	10.28	14.12	12.20b	3.85	6.60	5.22a
Sole Crotalaria	11.88	17.37	14.62a	4.56	6.86	5.71a
CSMz + 69 kg N ha^{-1}	8.74	12.22	10.47c	3.15	4.93	4.04b
CSMz + 0 kg N ha^{-1}	7.94	12.24	10.09c	1.95	4.15	3.05c
Mean	7.99b	12.06a		2.60b	4.88a	

Source: Tesfa et al. (2004), *CSMz: continuous sole maize, **Muc: mucuna, Cav: Canavalia, Crt: crotalaria, **ITEVS: intercropped at early vegetative stage and **ITFS: intercropped at flowering stage

Table 18. Biomass and grain yield of maize subsequently planted on previous fields of intercropped legumes on farms

Previous legume fields of intercrops Compared to CSMz*	46 kg N ha^{-1}	92 kg N ha^{-1}	Mean biomass yield in t ha^{-1}	46 kg N ha^{-1}	92 kg N ha^{-1}	Mean grain yield in t ha^{-1}
	Biomass yield t ha^{-1}			Grain yield t ha^{-1}		
Mz + Crt ITEVS**	11.14	12.52	11.83a	5.54	6.38	5.96a
Mz + Muc ITEVS**	12.12	12.58	12.35a	6.12	6.12	6.12a
CSMz*	10.65	11.57	11.11b	5.20	5.77	5.48b
Mean	11.30b	12.22a		5.62b	6.09a	

Source: Dennis et al. (2003), *CSMz: continuous sole maize, **Muc: mucuna, Crt: crotalaria, **ITEVS: intercropped at early vegetative stage and **ITFS: intercropped at flowering stage

2.5.2 Legumes N fertilizer replacement value

2.5.2.1 In-situ legume biomass production and N-accumulated

Study conducted on biomass N values and fixed N fertilizer values of three legumes at Jimma indicated that soybean had accumulated relatively higher biomass N-content of 3.58% but it produced lower biomass yield of 5.41tha^{-1} and it correspondingly gave N-yield of 194kg ha^{-1} (Table 19). Biomass of crotalaria and Sesbania had high respective N-contents of 2.85% and 3.24% (Table 19). Both produced higher biomass of 7.65t ha^{-1} and 7.86t ha^{-1}, respectively and gave corresponding N-yields of 218kg ha^{-1} and 255t ha^{-1} (Table 19). While FYM had lowest N-content of 1.28% and its rate used for comparison were five and ten ton per hectare had lower N-yields of 64 and 128 kg ha^{-1}., respectively.

2.5.2.2 N-contribution from fixation

Soybean, sesbaia and crotalaria were cropped as a preceding crops and maize was succeeded on the same field having application of four N-rates from urea. The succeeded maize grain yield was significantly increased due to the N-fixed by legumes (Table 20). The N-fertilizer contributed by fixation from all legumes namely; soybean, crotolaria and sesbania were equal to the grain yield obtained by applying 69 kg ha^{-1} N in plots of continuous maize (Table 20). N-fixed by legumes had 50% yield advantage over the plot of continuous maize without N-application and produced comparable yield to plots of continuous maize with recommended N. This implied that fixed N from sole legumes had potentials to substitute more than 70 kg urea-N ha^{-1}.

2.5.2.3 N-uses from biomass transfer

Five ton per hectare from dry biomass of sesbania, soybean and crotalaria were transferred and chopped down on other field and incorporate to soil a month before maize sowing. Due to incorporation of all legumes biomass significant increases of maize grain yield was recorded (Table 21). The yield advantage of biomass N was increased by 49% over the control and it rendered comparable yield to plots of continuous maize with recommended N. This implied that transfer of five ton per hectare biomass from all legumes had potentials to substitute more than 70 kg urea-N ha^{-1}.

Table 19. Total N-content, harvested biomass and total N-accumulated in biomass

Legumes, [1]FYM and Soil	Total N (%) *BSI	Total Soil N (%) **RMP	Total Soil N (%) ***MAME	Total Biomass Harvested tha^{-1}	Total Biomass N kgha^{-1}
Soybean	3.58	0.52	0.43	5.41	193.68
Crotalaria	2.85	0.74	0.52	7.65	218.02
Sesbania	3.24	0.78	0.51	7.86	254.66
FYM	1.28	0.27	0.19	5.00	64.00
FYM	1.28	0.46	0.32	10.00	128.00
Soil CMF****	0.11	0.13	0.12	-	-

Source: Tesfa et al. (2004), [1]FYM (farm yard manure), *BSI (Before soil incorporated), **RMP (Right at maize planting), ***MAME (month after maize emergence) and ****CMF (continuous maize field)

Table 20. Grain yield of maize (t ha^{-1}) influenced by mineral N fertilizer and the fixed N by legumes

N- levels Kg ha^{-1}	Preceding legumes			Continuous maize	Nitrogen mean
	Sesbania	Crotolaria	soybean		
0	7.03	7.10	6.71	4.69	6.38d
46	9.18	7.60	9.17	6.33	8.07c
69	10.78	9.07	9.67	6.62	9.04b
92	10.88	9.92	10.02	8.60	9.85a
Pl-mean	9.46a	8.42b	8.89ab	6.56c	

Source: Tesfa et al. (2004), Figures followed by the same letter are not significantly different at $p<0.05$

Table 21. Grain yield of maize (t ha^{-1}) influenced by mineral N fertilizer and the biomass N from legumes

N- levels Kg ha^{-1}	Preceding legumes			Continuous maize	Nitrogen mean
	sesbania	crotolaria	soybean		
0	9.19	8.41	8.40	6.12	8.00b
46	9.96	11.91	11.15	7.52	10.13a
69	11.06	11.30	11.21	8.07	10.41a
92	9.86	11.29	11.45	10.42	10.76a
Pl-mean	10.02a	10.98a	10.80a	8.03b	

Source: Tesfa et al. (2004), Figures followed by the same letter are not significantly different at p<0.05

At Areka, tithonia biomass at rates of 0, 2.5, 5 and 7 ton per hectare were transferred to maize fields and incorporated a month before maize sowing. These rates were used in combination with 0, 10, 20 and 30 kgha^{-1} P. Maize yield was significantly increased due to both fertilizer sources (Table 22). It was further notified that integrated application of 5 ton tithonia and 30 kg P ha^{-1} gave comparable maize yield with the recommended NP fertilizers of 64/20 kg NP ha^{-1}. Therefore, integrated uses of 5 ton tithonia with 30 kg Pha^{-1} could be advised for low cost and sustainable maize production at Areka.

Table 22. Mean grain yield of maize as influenced by application of tithonia at Areka

Tithonia t/ha	2007	2008	P kg/ha	2007	2008
0	4191b	386c	0	4435b	3686b
2.5	5198a	4529bc	10	4882b	4639ab
5	5289a	5084ab	20	5102ab	5442a
7	5371a	5794	30	5638a	5500a
LSD	68	1084	LSD	688	1085

Source: Anon (2007-2008)

2.6 Integrated use of crop residues and coffee by-product with NP fertilizer

Field trials with an objective to enhance low soil fertility of Haramaya soil types through integrated uses of crop residue and NP fertilizers were conduct at Haramaya on Rare experimental field from 1988-1994 (Heluf *et al.,* 1999). Recommended fertilizers rates for Haramaya series, 133/20 kgha^{-1} NP and for Haramaya black clay, 128/65 kgha^{-1} NP were tested at these full doses and one-half of both doses for each respective soil types. Maize residues at five ton per hectare were chopped in to pieces of 5-10cm and incorporated to soil during dry periods. Two of the plots where these residues incorporated received yearly the above NP rates and the rest two plots received only at the first year and a control plot that received only maize residues at the same rate per annum were also included as a treatment. A maize variety, EAH-75 was used as a test crop. Results across season and soil types showed that yearly application of NP fertilizers at both one-half and full recommended rates resulted in grain yield increases of more than 500 and 1100 kgha^{-1}, respectively over application of only crop residue (Table 23). Moreover, grain yield responses due to residual NP fertilizers applied only during the first year were found to be comparable to the yearly application of these fertilizers. Though seasonal rainfall trends governed maize yield response to fertilizers, Haramaya series generally gave higher grain yield than Haramaya Black clay (Table 23). Thus, on both soil types of Haramaya, yearly application of the full recommended doses of NP fertilizers integrated with five ton per hectare crop residue are advised to improve the fertility of these soils for sustainable maize production in the area.

Table 23. Across season mean grain yield and correlation coefficient (r) between rainfalls and mean grain yield

Treatments	Haramaya series (*Typic Ustorthent*)		Haramaya black clay (*Ttypic Pellustert*)	
	Grain yield, kg/ha	Rainfall x Yield (r)	Grain yield, kg/ha	Rainfall x Yield (r)
CRYA	2269d	0.89*	1611c	0.63*
CR + HRRNPYA	2709bc	0.90*	2158b	0.82*
CR + FRRNPYA	3115a	0.97*	2917a	0.91*
CRYA + HRRNPO	2555c	0.86*	1845c	0.63*
CRYA + FRRNPO	2835b	0.89*	2153b	0.77*

Source: Heluf et al. (1999), CR (crop residue), YA (yearly application), HRR (one-half recommended rate), FRR (full recommended rate), NP (nitrogen and phosphate) O (only first year) and * (significantly correlated at P0.05)

At Hawassa, integrated uses of coffee by product and N fertilizer were evaluated to enhance low soil fertility and produce information on low input maize cropping system. Combinations of different rates of coffee by product and N rates were tested in maize-common bean intercropping system. Significant increment of grain yield of maize was obtained where nine ton per hectare coffee residue without N fertilizer applied. The same treatment had yield advantage of 91% over the control (Table 24). While N fertilizer alone accounted for 149%

yield advantage over the control. Likewise, combinations of coffee by product and nitrogen had greater yield advantage up to 213% over the untreated control. Application of N fertilizer raised the uptake of N up to 60 kg ha^{-1}. Therefore, coffee growers in southern region can sustain their maize production system through integrated uses of 90 kg N ha^{-1} with six ton ha^{-1} coffee by product.

Table 24. Effect of coffee by product and N fertilizer on grain yield (kg ha^{-1}) of intercropped maize

Coffee by product ($t\ ha^{-1}$)	N fertilizer (kg ha^{-1})				
	0	30	60	90	Mean
0	1541	3540	3911	4044	3259 b
3	2237	3600	1985	3244	2766 c
6	2800	3289	2755	3866	3177 b
9	3807	3348	3659	4133	3737 a
Mean	2596 d	3444 b	3077 c	3822 a	

Source: Tenaw et al. (2006), same letters denote no significant difference between treatments ($P \geq 0.05$).

3. Conclusion

Maize production in Ethiopia has been facing critical constraints due to gradual decline of soil fertility. To alleviate this chronic problem of maize production in the country, a number of fertilizer research attempts have been conducted on maize at different research institutions. The research outputs of various institutions in the country confirmed variable results because of differences in soil types, agro-ecology, varieties used and crop management systems.

Although, the escalating costs of inorganic fertilizers may not encourage the resource poor farmers to use the full dose of fertilizers recommended for their crops. Thus, to offer low input technology on soil fertilization, research efforts has been made on integrated uses of different source of organic and inorganic fertilizers. Accordingly, maize sown in rotation with nug and soybean at Bako and Jimma, respectively required one-half of the recommended fertilizer rates that crop rotations offset 50% of fertilizer cost. Maize planted using combinations FYM, compost and biogas effluent with lower rates of NP fertilizers at Bako gave comparable yield to the recommended NP rates. Another attractive research on uses of legumes as short fallows and green manuring indicated that *Dolichos lablab* and mucuna at Bako and crotalria, sebania and mucuna at Jimma planted as preceding crop could partially or fully replace the N-fertilizer need of subsequently sown maize. Similarly, five ton per hectare tithonia biomass integrated with 30kg P ha^{-1} brought an increment in maize yield that was comparable to maize produced using recommended NP rate. At Haramaya, yearly combined application of crop residue with full NP rates and at Areka also nine ton/ha coffee by product combined with 60 kg N ha^{-1}enhanced soil fertility and promised sustainable production of maize in respective location.

Therefore, the integrated use of mineral fertilizers with FYM, compost and biogas effluent should be promoted in potential maize agro-ecologies. Legume for short fallows and green manuring are found easy to use at low and intermediate technology levels and must be included in maize production packages and soon taken up through government extension services. Likewise, potential grain legumes and also forage and fodder legumes must be utilized in rotation with maize to enhance soil fertility and to produce maize at low cost, while giving human food and animal feed in maize based farming system in Ethiopia.

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