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RAINWATER MANAGEMENT AND SOIL IMPROVEMENT TECHNIQUES IN MAIZE-SOY BEAN INTERCROP

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Abstract
Constraints, opportunities and strategies along maize-soy bean value chain were identified in two districts (Lawra and Tolon) in the Volta River basin of Northern Ghana. Identified constraints which required technological solutions were low rainfall (drought) and poor soils. Rain water management and soil improvement techniques were identified as solutions to these constraints. On-farm trials specifically tested the effect of rainwater management techniques (tied ridges and contour bunds) and soil fertility improvement methods (organic and inorganic fertilizers) on grain and biomass yields in a maize-soy bean inter crop at these two districts. This was part of a more elaborate gender sensitive study that sought to integrate livestock and biomass production into improved rainwater management cropping system that took cognizance of the influence of institutions and markets as well as the various value chain actors. These trials were replicated on-station at Nyankpala Animal Research Institute in Tolon district with two additional treatments. A completely randomized experimental design was used. Mean combined grain yield in Tolon was significantly higher than ($P<0.05$) in Lawra. The same pattern was observed for combined biomass yield, maize grain yield, soy grain and biomass yields. Gender did not seem to play a role in yield quantities except for soy grain and biomass yield. Tied ridges or contour bunds with organic and inorganic fertilizer had better maize grain and biomass yield as compared to the control. Similar trends were observed on-station. There were no treatment effects on soy. Combined rainwater management and soil fertility improvement techniques had better effect on maize grain and biomass yields. Total grain sale minus input cost per treatment plot varied between the study sites and was found to be more positive for all treatments at Tolon compared to Lawra.

Keywords: biomass, intercrop, tied ridges, volta basin, organic manure.

1.0 INTRODUCTION

Over 50% of the world's crop and livestock products come from crop-livestock systems of smallholder farmers in developing countries, and trends indicate that they would continue to play a major role in world food production (ETC group, 2009). Population is expanding at an annual growth rate of 2.1% in Ghana (IFAD, 2009), thus increasing the pressure on natural resources for livelihoods and economic gains (Kitzes et al., 2008). Of this population, 76% rely on rain fed crop-livestock systems for their livelihoods in Ghana (Thornton et al., 2002). The frequency of annual droughts, unpredictability of the onset and establishment of the rainy season, erratic rainfall and extreme seasonal hot temperatures has increased from the 1970s and will likely become worse in the future (Battisti and Naylor, 2009; Kasei et al., 2010). Growing crop and livestock markets which is as a result of increasing human population is an opportunity that could be of benefit to smallholder farmers. With regard to these driving forces there is increasing urgency for farming systems to become more productive in ways that are sustainable, acceptable by rural smallholders and meet growing demand for food. In this respect, improvements in rainwater and nutrient management in mixed crop-livestock agro ecosystems are essential. Efforts have been made in soil and water conservation measures, nutrient management strategies, improved crop varieties and rainwater management solutions all aimed at improving crop-livestock system productivity (Douxchamps et al., 2012). However these problems continue to

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linger suggesting poor uptake of technologies (Kavoi et al., 2014). Until recently, strategies adopted mono disciplinary approaches as opposed to integrating key disciplines (Anandajayasekeram et al., 2008). For example, often priority is given to crops to the neglect of livestock even though livestock constitute an essential component of mixed systems (Amankwah et al., 2012). Also interventions did not seek full participation of key actors and stakeholders in arriving at priority interventions. Therefore, there is poor targeting of interventions to specific biophysical and socioeconomic domains. Market drivers are not properly analyzed and the effect of institutional environment and policies are often given little thought. This study specifically tested the effect of rainwater management and soil fertility improvement techniques on grain and biomass yield in maize-soy bean inter crop in the Volta River Basin of Northern Ghana. This was part of a more elaborate gender sensitive study that sought to integrate livestock and biomass production into improved rainwater management cropping system that took cognizance of the influence of institutions and markets as well as the various value chain actors.

2.0 MATERIALS AND METHOD

2.1 Experimental Farmers

Village farmers developed their own criteria for selecting farmers who would be directly involved in the experiment. Each village had eight experimental farmers consisting of four men and four women.

2.2 Treatment Identification

A Participatory Action Research (PAR) was adopted which entailed engaging multi-stakeholders such as farmers, researchers and agricultural extension agents in designing and implementing on-farm and on-station research. Innovation platforms, which are an assembly of multi-stakeholders along crop-livestock value chains, were established in the two study districts. Constraints, opportunities and strategies at various levels along each value chain were identified and these formed the basis for formulating, in a participatory approach, the relevant action research questions and how they would be tested. Constraints identified in the maize-soy value chain which required technological solutions in the project villages were low rainfall (drought) and poor soils. The IP members identified and agreed to use the following interventions: tied ridges (Figures 1 & 2) and contour bunds (Figure 3) which were rain water and soil water management techniques, and organic manure and mineral fertilizers which on the other hand were soil fertility improvement techniques. A PAR protocol was then developed.

Figure 1: Tied ridges with rainwater

Figure2: Crops growing on tied ridges

Figure3: A contour bund

2.3 Experimental Design

Each experimenting farmer offered half an acre of land for this experiment. The half acre land was divided into fifteen (15) equal subplots with each subplot measuring 10m x 10m**.** There were five treatments (Table 1) which were replicated three times on each farmer's plot. Four different plot designs were randomly generated and two farmers were randomly selected in each village to try each design. Treatments were completely randomized on each plot. All eight farmers in each village tested all five treatments replicated three times on their plots.

All sowed Pannar-53 maize (a South African Hybrid variety) and Jenguma soy bean variety (a Council for Scientific and Industrial Research (CSIR)-Savanna Agricultural Research Institute (SARI) variety) in an intercrop. Inter row spacing was 75cm x 25cm intra cropped (maize) with two soy plants intercropped equidistant, on the row/ridge. Tied ridge treatments were tied at 75cm. Contour bunds were made across slope in treatments plots that required this. Organic manure which was obtained by the farmers were heaped on designated subplots, evenly spread and ploughed into the soil. Organic manure and/or mineral fertilizers were applied to treatment subplots as required (Table 1).

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The experiment was repeated on-station at CSIR-Animal Research Institute (ARI), Nyankpala station (GPS coordinates 09^0 24'27.6"N 000^0 59'07.6"W) in Tolon District with two additional treatments (Treatments 6 and 7, (Table 2), as a check and used as learning site for PAR actors.

Table 1: Explanation of treatments applied on-farm

Treatment	Soil water management		Soil fertility management	
	Tied ridges	Contour bunds	Organic manure (farm yard) 4,000kg/ha	Inorganic fertilizers NPK 15-15-15,(125kg/ha), SA 62.5kg/ha
T1 Farmer practice				
T2	√		√	
T3		√	√	
T4	√		√	√
T5		√	√	√
All farmers sowed maize/soybean intercrop				

Table 2: Explanation of treatments applied on-station

Treatment	Soil water management		Soil fertility management	
	Tied ridges	Contour bunds	Organic manure (farm yard) 4,000kg/ha	Inorganic fertilizers NPK 15-15-15,(250kg/ha), SA 125kg/ha
T1 Farmer practice				
T6	√			√
T7		√		√
All treatment plots had maize/soybean intercrop				

2.4 Data Collection and Analysis

The following dependent variables were monitored and results obtained.

- Net grain yield (maize and soy bean)
- Crop residue yield (bulk dry matter)

For determination of net grain yield and bulk dry matter, yield data was collected from the four villages by subplot by farmer by bulk harvest of six middle rows of every subplot

Total grain sales (maize and soy grain), minus input cost per treatment subplot was calculated for all treatments and results shared on the various innovation platforms.

With the on-farm data, the response variables of interest were maize grain yield, maize biomass yield, soy grain yield and soy biomass yield. The data were analyzed using the General Linear Model (GLM) procedure of SAS 2008. Fixed effects fitted in the model included the effects of district (Lawra, Tolon), village (Orbili, Naburnye, Golinga, Digu), gender (male, female) and treatments (T1, T2, T3, T4, T5). Student Newman Keuls (SNK) test was used to separate means of effects with three or more levels which were significant in the least squares analysis of variance. The statistical model was explained as follows:

$Y_{ijklm} = \mu + D_i + V_j + G_k + T_l + e_{ijklm}$

Where

Y_{ijklm} = the m^{th} yield of the l^{th} treatment of the k^{th} gender at the j^{th} village in the i^{th} district

μ = overall mean

D_i =fixed effect of the i^{th} district

V_j = fixed effect of the j^{th} village

G_k = fixed effect of the k^{th} gender

T_l = fixed effect of the l^{th} treatment

e_{ijklm} = random error

Also with the on-station data the response variables analyzed were maize grain yield, maize biomass yield, soy grain yield and soy biomass yield. The data were analyzed using the GLM procedure of SAS (SAS, 2008). Only one fixed effect was fitted in the model and this was treatment (T1, T2, T3, T4, T5, T6, T7). SNK was used to separate the means which were significant in the least squares analysis of variance.

The statistical model was explained as:

$Y_{ij} = \mu + T_i + e_{ij}$

Where Y_{ij} = the j^{th} yield resulting from the i^{th} treatment

μ = overall mean

T_i =fixed effect of the i^{th} treatment

e_{ij} = error term associated with the yield

3.0 RESULTS AND DISCUSSION

3.1 Grain and Biomass Yields at Lawra Site

By village, in Lawra District, Naburnye had a mean combined grain yield (maize and soy grain yields added) of 1670.1kg/ha, which was higher than ($P<0.05$) the mean combined grain yield for Orbili 1266.6kg/ha. The same trend was observed for the mean combined biomass yield, presented in Table 3. Maize grain and biomass yields in Naburnye were also significantly higher than those of Orbili ($P<0.05$). Soy grain and biomass yields in Naburnye on the other hand were not significantly different from the same in Orbiili. Female farmers had significantly higher combined grain yield (maize and soy) than males. They also had a higher maize grain yield than the males, though not significantly different. However, soybean grain and biomass yields were better for males than females ($P<0.05$). Combined rainwater management and soil fertility improvement techniques had better effect on grain and biomass yields for both crops. Tied ridges combined with organic matter were found to be particularly beneficial to soybean grain and biomass yields. According to Wakene et al. (2007), supplementing Inorganic Fertilizer (IF) with low doses of Nitrogen-Phosphorus (NP) fertilizers or Farm Yard Manure (FYM) also increased grain yield. Maize grain yield among supplemented IF with NP or FYM ranged between 5910kg/ha to 6006kg/ha which were statistically not significant to each other. The lowest grain yield was recorded from the control treatment followed by the recommended NP fertilizers. Oad et al. (2004) observed similar trends.

Table 3: Grain and biomass yield by village, gender and treatment in Lawra District

Village	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
Orbilli	1266.6^{b}	1059.8^{b}	206.82	2801.0^{b}	2502.1^{b}	317.72
Naburnye	1670.1^{a}	1464.6^{a}	213.10	3617.0^{a}	2927.9^{a}	358.86
Gender	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
Male	1240.0^{b}	1086.5	236.18^{a}	3115.7	2721.0	370.67^{a}
Female	1459.5^{a}	1271.7	187.77^{b}	2941.2	2552.4	295.78^{b}
Treatment	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
1	717.6^{b}	565.2^{b}	153.08^{b}	2202.9^{b}	1572.4^{b}	248.99^{b}
2	1079.0^{b}	808.1^{b}	236.23^{a}	2509.4^{b}	2129.2^{b}	365.61^{a}
3	870.6^{b}	644.4^{b}	216.93^{ab}	2015.1^{b}	1637.5^{b}	343.08^{a}
4	2047.8^{a}	1964.4^{a}	202.32^{ab}	4249.0^{a}	3929.4^{a}	316.99^{ab}
5	2020.2^{a}	1810.3^{a}	228.97^{a}	4093.0^{a}	3680.8^{a}	357.51^{a}

Means with different superscripts in the same column differ significantly ($P<0.05$)

T1 = Control; T2 = Tied ridges with organic matter; T3 = Contour bund with organic matter; T4 = Tied ridges, organic and inorganic fertilizer; T5 = Contour bunds, organic and inorganic fertilizer

3.2 Grain and Biomass Yields at Tolon Site

Golinga village in Tolon District had a mean combined grain yield of 3038 kg/ha, which was higher than ($P<0.05$) the mean combined grain yield for Digu 1174.2 kg/ha, presented in Table 4. Maize grain yield in the two villages were not significantly different while soy grain yield was significantly higher at Golinga ($P<0.05$). There was a preponderance of sandy loam at Golinga compared with Digu. At Digu loamy sand was more common. The reverse was true for maize biomass yields in these two villages ($P<0.05$). There was no significant difference between soy biomass yields. Male farmers had better combined grain and biomass yields and soybean yields than females ($P<0.05$) but this was not the case with maize only. Combined rainwater management and soil fertility improvement techniques had better effect on grain and biomass yields. It appears that in Tolon, the interventions were more effective for maize grain yield than soybean grain and biomass yields ($P<0.05$). While grain yields were responding to the treatments all the biomass yields (maize and soybean) did not seem to be affected by the treatments.

Table 4: Grain and biomass yields by community, gender and treatment in Tolon District

Community	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
Digu	1174.2^{b}	1441.1	369.78^{b}	6955.6^{b}	2906.7^{a}	4977.8
Golinga	3038.1^{a}	1457.1	1085.98^{a}	7659.8^{a}	2187.6^{b}	5046.0
Gender	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
Male	2513.2^{a}	1481.9	1243.02^{a}	8016.1^{a}	2570.0	6023.1^{a}
Female	2250.4^{b}	1393.4	617.47^{b}	6951.4^{b}	2657.4	3985.0^{b}
Treatment	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
1	1933.3^{b}	811.8^{c}	992.39	6855.6	1923.3	5071.4
2	2447.1^{ab}	1474.3^{b}	879.08	7533.3	2871.5	4887.4
3	2440.8^{ab}	1085.7^{c}	1028.04	7663.8	2276.4	5434.5
4	2672.6^{a}	1922.2^{a}	956.45	7700.0	2847.6	5182.2
5	2401.5^{ab}	1892.6^{a}	842.66	7666.7	3079.4	4595.6

Means with different superscripts in the same column differ significantly (P<0.05)

T1 = Control; T2 = Tied ridges with organic matter; T3 = Contour bund with organic matter; T4 = Tied ridges, organic and inorganic fertilizer; T5 = Contour bunds, organic and inorganic fertilizer

3.3 Overall Mean Grain and Biomass Yields for Lawra and Tolon Districts

Mean combined grain yield (maize and soy grain yield added) in Tolon was significantly ($P<0.05$) higher than in Lawra, 2387.91 kg/ha and 1365.44 kg/ha respectively (Table 5). The same pattern was observed for combined biomass yield (maize and soy biomass yield added), maize grain yield, soy grain yield and soy biomass yield ($P<0.05$). Average maize and soy grain yields according to the Ghanaian Ministry of Food and Agriculture (MoFA, 2011) for Lawra District were 660kg/ha and 1210kg/ha respectively, implying that treatment effect almost doubled the maize yield for Lawra compared with MoFA figures. In this regard there were no treatment effects on soy bean in Lawra District. Lawra District is a drought-prone area with shallow soils compared to Tolon District. The principal benefits of tied-ridges on soils with positive response were attributed to moisture conservation (FAO, 1995). Araya and Stroosnijder (2010) noted that Grain yields were increased by the use of tied ridges. The effect of the tied ridges in increasing grain yields was generally better in the drier periods and the more so when the ends of the ridges were tied.

Table 5: Analysis of Grain and biomass yields by districts, Lawra and Tolon

District	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
Tolon	2387.91^{a}	1446.21^{a}	938.81^{a}	7479.2^{a}	2606.5	5032.0^{a}
Lawra	1365.44^{b}	1191.21^{b}	208.33^{b}	3020.0^{b}	2632.5	327.6^{b}

Means with different superscripts in the same column differ significantly ($P<0.05$)

Golinga, in Tolon District, had a mean combined grain yield of 3038kg/ha, which was higher than the mean combined grain yield for the other three communities (Naburnye 1670.1kg/ha, Orbili 1266.6kg/ha, in Lawra District, Digu 1174.2 in Tolon) ($P<0.05$), presented in Table 6. This trend was the same for soy grain yield and combined maize and soy biomass yield.

Table 6: Analysis of Grain and biomass yields by project villages, in Lawra and Tolon Districts

Village	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
Digu	1174.2^{c}	1441.1^{a}	369.78^{b}	6955.6^{b}	2906.7^{a}	4977.8^{a}
Golinga	3038.1^{a}	1457.1^{a}	1085.98^{a}	7659.8^{a}	2187.6^{b}	5046.0^{a}
Orbili	1266.6^{c}	1059.8^{b}	206.82^{c}	2801.0^{d}	2502.1^{b}	317.7^{b}
Naburnye	1670.1^{b}	1495.1^{a}	213.10^{c}	3617.0^{c}	2927.9^{a}	358.9^{b}

Means with different superscripts in the same column differ significantly ($P<0.05$)

Gender did not seem to play a role in yield quantities except for soy grain and biomass yields where the males had higher yields than ($P<0.05$) the females (Table 7). The significantly higher soy biomass yield observed for males translated into an observed higher combined biomass yield for males ($P<0.05$).

Table 7: Grain and biomass yields by gender, Lawra and Tolon Districts

Gender	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
Male	1770.49	1323.20	787.37[a]	5268.9[a]	2628.6	3465.1[a]
Female	1718.93	1327.48	384.60[b]	4529.2[b]	2605.5	1985.7[b]

Means with different superscripts in the same column differ significantly (P<0.05)

Tied ridges with organic and inorganic fertilizer (Treatment 4) and contour bunds with organic and inorganic fertilizer (Treatment 5) had better maize grain and biomass yield, either combined or grain or biomass yields only as compared to Treatments 1, 2 and 3.(P<0.05). There was no significant difference between Treatments 4 and 5 even though Treatment 4 apparently had higher grain and biomass yields (Table 8). Rain water management methods (contours and tied ridges) did not have any significant effect on soy (a legume) grain or biomass yields. The same was observed on *Stylosanthes* hamata by Hulugalle (1989). He observed that tied ridges significantly increased grain and dry matter production of maize but did not affect that of *Stylosanthes* hamata. Grain and dry matter yield of maize in tied ridged plots were reduced by under sowing with *Stylosanthes* hamata only when drought occurred during reproductive and late vegetative growth, respectively. In open ridged plots, dry matter and maize yield were not affected by the cropping system. Highest total dry matter production was observed in under sown, tied ridged plots.

Table 8: Grain and biomass yields by treatments, for Lawra and Tolon Districts

Treatment	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
1	1159.7[c]	709.5[c]	580.36	4161.9[b]	1775.8[c]	2704.0
2	1584.6[b]	1156.1[b]	557.65	4624.7[b]	2546.1[b]	2626.5
3	1450.9[b]	874.9[c]	622.48	4377.3[b]	1996.4[c]	2888.8
4	2277.3[a]	1942.7[a]	573.20	5702.0[a]	3331.6[a]	2709.7
5	2163.2[a]	1853.3[a]	535.82	5522.5[a]	3344.0[a]	2476.5

Means with different superscripts in the same column differ significantly (P<0.05)

Similar trends were observed on-station where two additional treatments were added (Table 9). These two additional treatments, tied ridges with only inorganic fertilizer (T6) and contour bunds with only inorganic fertilizer (T7) proved superior to all other treatments. Inorganic fertilizer levels were twice those of T4 or T5. Better rainwater conservation methods (contours and tied ridges) coupled with increased inorganic fertilizer levels could be the contributing factor, as observed by (Friesen and Mduruma, 2009). Compared to flat or open ridged fields, tied ridges were shown to result in yield increases of about 40% in maize trials with improved varieties. Similar increases in grain yield of about 63% and 37% were observed up from 30% and 23%, respectively using the maize varieties ACV-6 and Melkassa-1 released in Ethiopia (Friesen and Mduruma, 2009). Gebrekidan and Uloro (2011) also reported that the magnitude of the yield response and the relative efficiency of the tied ridges and planting methods varied with soil type, fertilization, and the total amount and distribution of rainfall during the cropping season.

Manure, when applied to soybeans, may improve soybean crop performance and yield compared to soybeans fertilized with commercial fertilizer or unfertilized soybeans (Helmers et al., 2008), While the literature reviewed clearly showed that the use of manure fertilizer was beneficial to soybean production, some instances where manure could inhibit soybean performance were also reported. These potential concerns included increased lodging, poor performance in fields with a history of white mold problems and increased occurrences of some fungal soybean diseases (Oelke, 1998; Schmidt et al., 2001). Soy did not respond positively to organic or inorganic fertilizer either on-station or on-farm.

Table 9: Analysis of Grain and biomass yields by Treatments at ARI, Nyankpala Station in Tolon District

Treatment	Grain yield (kg/ha)			Biomass yield (kg/ha)		
	Maize + soy	Maize	Soy	Maize + soy	Maize	Soy
1	1804.4^{d}	1431.1^{de}	373.3	8378^{ab}	3066.7^{bc}	5311.1
2	1615.5^{d}	1120.0^{e}	282.2	7311^{b}	2822.2^{c}	4488.9
3	2444.4^{cd}	2000.0^{cd}	444.4	9889^{ab}	3977.8^{abc}	5911.1
4	2857.8^{bc}	2400.0^{c}	457.8	11178^{a}	5133.3^{ab}	6044.5
5	3011.1^{bc}	2733.3^{bc}	277.8	10022^{ab}	5133.4^{ab}	4888.9
6	3820.0^{ab}	3377.8^{ab}	442.3	9689^{ab}	4777.8^{abc}	4911.1
7	4095.6^{a}	3755.6^{a}	340.0	10667^{ab}	5666.7^{a}	5000.0

Means with different superscripts in the same column differ significantly (P<0.05)

T1 = Control; T2 = Tied ridges with organic matter; T3 = Contour bund with organic matter; T4 = Tied ridges, organic and inorganic fertilizer; T5 = Contour bunds, organic and inorganic fertilizer; T6 = Tied ridges and inorganic fertilizer; T7 = contour bunds and inorganic fertilizer

3.4 Total Grain Sales (Maize and Soy) minus input cost per treatment plot for the two Study Sites

Total grain sales (maize and soy) minus input cost per treatment plot analysis (per hectare) of all treatments (Table 10) demonstrated to the rural resource poor the practical realities of which treatment(s) to adopt and/or adapt. For all participating farmers, total grain sales (maize and soy) minus input cost per treatment plot of Treatment 1 (farmer practice) turned out with the least value of -US$8.00 profit while Treatment 5 had the highest profit of US$116.00 as shown in Table 10. However, this trend was found also to vary with the individual participating farmers. This was the case with Madam Augustina Dabuo, farmer number 25 in Lawra District who recorded appreciable profits for all the treatments (T1 = $428.00, T2 = $587.00, T3 = $240.00, T4 = $568.00 and T5 = $561.00), probably due to her field history of good husbandry practices. There were indications of more profits in Tolon site.

Table 10: Treatments and Profits per Hectare by study sites for Farmers Experimenters

Treatment	Profit (US$) across sites combined (N=28)	Profit (US$) for Lawra site (N=12)	Profit (US$) for Tolon site (N=16)
T1	-8.00	-64.00	32.00
T2	61.00	-19.00	123.00
T3	16.00	-59.00	73.00
T4	56.00	84.00	34.00
T5	116.00	62.00	156.00

N=Number of farmers used in computation; US$1.00 = GH¢1.95

4.0 CONCLUSION

Combined rainwater management and soil fertility improvement techniques had better effect on maize grain and biomass yields likely to reduce yield gaps for food security. In Tolon, the treatments seemed to be particularly important for significant increases in maize grain yield while in Lawra, they were necessary for increasing both grain and biomass yields.

Biomass generated provides potential for addressing livestock dry season feed supplementation needs as well as improving and sustaining soil fertility in the crop-livestock systems. Across board recommendation of the rainwater management strategies for all sites might not yield equal economic benefits.

In the event of making economic decisions to guide their farming operations, farmers in Tolon site appeared to have a better basket of options for possible adoption. The same cannot be said of farmers in Lawra location who may have to focus more on contour bunds or tied ridging integrated with the use of organic and mineral fertilizers in order to operate profitably at farm level.

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