

Effects of organic manure and crop rotation system on potato (*Solanum tuberosum* L.) tuber yield in the highlands of Awi Zone

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ABSTRACT

Lack of sustainable soil fertility management system is a critical challenge in the highlands of Awi Zone. Important physicochemical properties of the soil are below the critical level to support crop growth. Hence, a study was undertaken with the aim of improving the yield of potato through organic treatments and sound crop rotation system. Two rotation systems and four levels of organic treatments were factorially arranged and laid out in RCBD with four replications. The organic treatments were: V1 = 0 t/ha farmyards manure (FYM); V2 = 2.5 t/h fresh sesbania green manure (FSB) V3 = 5 t/ha FYM; and V4 = 5 t/ha FYM +2.5 t/ha FSB applied in fixed plots for three years. Indeed, the rotation systems varied from year to year to estimate the changes in potato tuber yields due to the differences in crop rotation systems. Tuber yields of potato showed increasing trend over the period of the three years with the lowest in the first year, intermediate in the second year and the highest in the third year across all treatments. Among all, the highest total potato tuber yield (35.15 t/ha) was obtained at the combined application of 5 t/ha FYM +2.5 t/ha FSB and clover-wheat-potato rotation system in the third year. The treatment combination increased total potato tuber yield by 140% and 41% over that of the first and the second years and would be recommended as ecologically sound option in improving the productivity of potato.

Keywords: Cropping system; farmyard manure; green manure; productivity; soil management

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INTRODUCTION

The highlands of Ethiopia account only 44% of the total area of the country, “although 90% of the human and 75% of the livestock population of the country is found in them” (Mohammed Gedefaw and Teshome Soromessa, 2015). The unbalanced livestock and human population pressure resulted in severe land degradation and soil nutrient depletion that has attributed to low agricultural productivity (Amare *et al.*, 2006). Similarly, in the highlands of Awi Zone exploitative conventional agricultural practices such as continuous cropping with the entire removal of crop residues, abandoning of fallowing, reduced use of manure

and crop rotation are further impoverishing soil resources of the region (Yazie Chanie, 2009). Tilahun *et al.* (2007) indicated that the use of dry animal manure and crop residues for the household energy source is also partly responsible for the declining of soil fertility in the highlands of Awi Zone.

Potato (*Solanum tuberosum* L.) is a very important crop in the highlands of Awi Zone. It has been widely renowned for improving the livelihood of smallholder farmers and sustains their food security at the household level (Glidermacher *et al.*, 2009). However, the average national productivity of potato (11.07 t/ha) remains

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stagnant which is far below that of the world's average productivity of 17.67 t/ha (FAOSTAT, 2013). Lack of sustainable soil fertility management is partly responsible for the lower productivity of potato in the country in general and in Awi Zone in particular (Tilahune *et al.*, 2007; Glidermacher *et al.*, 2009; Hirpa *et al.*, 2010).

Attempts to optimize sustainable nutrient supply in potato fields need diverse approaches of using organic inputs (Najme *et al.* 2013). Focusing on utilizing organic inputs are the key solution to reverse the declining trend of soil fertility, environmental threat and ultimately improve the profitability and the yield quality of potato (Goffart and Olivier, 2008). In cultivated lands, the primary organic input sources are the *in-situ* maintenance of crop residues and addition of farmyard manure to the soil. Another potential source of organic fertilizer in the present study area is using green manure such as clover and lupine undersowing with cereals or grown in pure stands in the rotation system. The important soil quality parameters such as the organic matter of the soil, soil nutrients, soil aeration and water holding capacity would be improved that in turn make the crop production more sustainable (Ndayegamiye *et al.* 2017). Hence, complementing of organic fertilizers with sound crop rotation systems would make the cropping systems more sustainable over the use of synthetic fertilizers.

Several research results underscore the importance of adding organic fertilizer in improving the yield of potato. Malihe *et al.* (2015) showed that application of farmyard manure at 40 t/ha significantly increased the tuber yield of potato (40 t/ha) by four folds over the yield (10.5 t/ha) on the unfertilized control. Similarly, Nooruldeen and Hiawe (2015) reported that application of well-

prepared organic fertilizer at the optimal rate (20 t/ha) gave an equivalent tuber yield of potato to that of 100% mineral fertilizer. In addition, Sayed *et al.* (2014) indicated that organic production of potato using 23.8 t/ha of compost could be an alternative to the conventional production with commercial organic fertilizers without significant reduction in yield and quality.

Like that of farmyard manure, green manure in pure stand or in undersowing culture improved the tuber yield of potato by improving the fertility and ameliorating soil physical properties of the cultivated lands (Malihe *et al.* 2015). Eugenija *et al.* (2014) reported that the greatest tuber yield of potato was obtained after clover than barley rotation system. Similarly, Malihe *et al.* (2015) found that potato plants grown in plots following common vetch and faba bean produced 12.7% and 15.0% more tuber yield, respectively, compared with that of winter wheat. Stefano *et al.* (2010) indicated that clover green manure and farmyard manure substantially increased the total yield by 22.5% and 25.1%, respectively, over the untreated control.

In the same way, farmyard manures and green manure crops are widely available in Awi Administrative Zone. Clover, lupine and sesbania have long been grown for years and can easily be used as green manure for potato production. Due to their very deep root penetration nature, high root biomass and ability to fix nitrogen biologically, inclusion of clovers in crop rotation schemes can play a great role in improving the properties of soils (Ruser *et al.*, 2008). In low input cropping systems in general using organic fertilizers and sound crop rotation system may remarkably be improving crop productivity including potato on a more sustainable way. However, due to lack of

awareness and intensive promotion of mineral fertilizer by extension system, the organic sources of fertilizers are not properly functioning in Awi Zone. Organic fertilizers are commonly used for other purposes such as fuel wood and plastering of houses than as source of nutrients. In addition, mono and continuous cropping are the dominant cropping systems in the study area which further diminish the fertility status of this area. In general, farmers of the locality have little experience in cultivating potato using their own farm resources. They rather rely on commercial sources of fertilizer which has a bearing on the sustainability of potato production.

In view of these backgrounds, the present study was initiated to assess the potential of organic treatments and sound crop rotation system

without applying synthetic commercial fertilizers for improving the productivity of potato in the highlands of Awi Agro-Ecological Zone.

MATERIALS AND METHODS

Descriptions of the Study Area

The present study was carried out both at on-station and on-farm in Gusha Shinkurta rural village of Guagusa District, Awi Zone from 2013 to 2015. Geographically, the study area is located in northwestern Ethiopia in the ranges of 11°92' to 11°91' N latitude and 28°61' to 28°87' E longitude. The altitude of the area ranges from 2451 to 2537 meters above sea level with a slope of 2.6 to 3.7% (Figure 1).

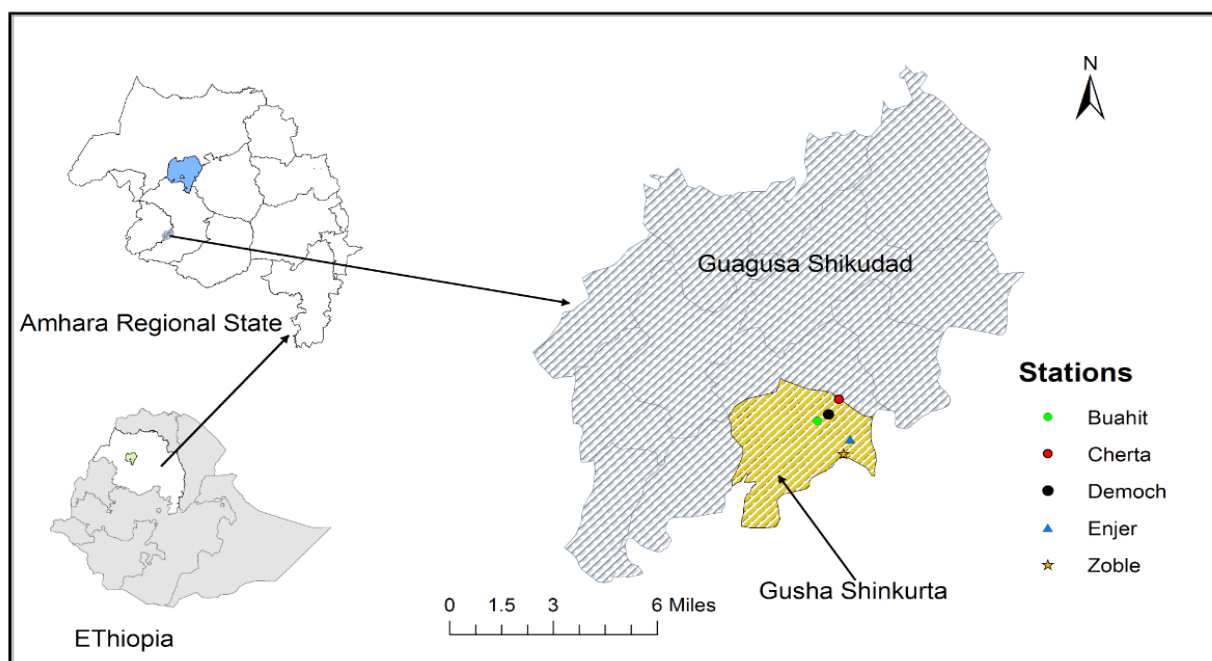


Figure 1: Location map of Guagusa Shikudad District, Gusha Shinkurta Village

The temperature of the area is cool with average night and day temperature of 10.2°C and 22.4°C, respectively. Its average mean annual rainfall is

2491.9 mm with mono-modal system extended from March to the end of November while the peak is in July and August (Figure 2).

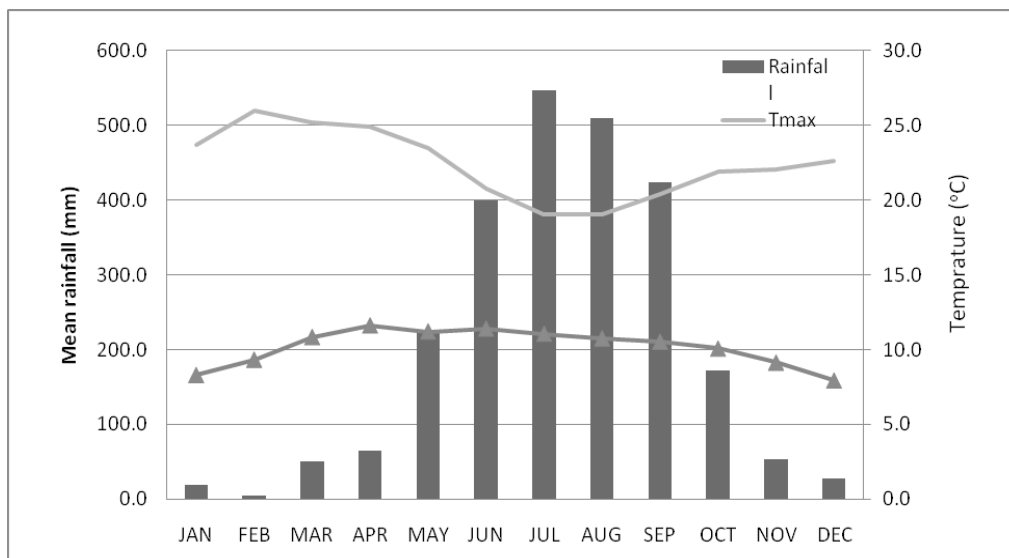


Figure 2: Average monthly rainfall and minimum and maximum temperatures of Gundile (nearby station)

The important physicochemical properties of the experimental soil were taken following the standard methods and procedures. Composite soil

samples were initially taken just before starting the study at the plow depth of 0-20 cm and the results are presented in Table 1.

Table 1: Initial physicochemical properties of the experimental soil before commencing the study

Soil parameters	Station	On-farm	On-farm	On-	On-	Means	Category
		Site-1	site-2	farm	farm		
				Site-3	Site-4		
Total nitrogen%	0.13	0.11	0.12	0.10	0.14	0.12	low
Available P (PPM)	9.54	8.44	8.98	7.84	9.30	8.64	low
Exc. K cmol(+) kg ⁻¹ soil	0.68	0.65	0.65	0.70	0.71	0.68	low
Organic carbon (%)	1.30	1.23	1.22	1.23	1.32	1.26	low
Organic matter (%)	2.25	2.15	2.14	2.17	2.36	2.21	low
pH (H ₂ O)	5.36	5.17	5.12	4.90	5.41	5.19	strong
CEC cmol(+) kg ⁻¹ soil	16.10	14.08	16.66	13.96	17.40	15.64	moderate
Bulk density g cm ⁻³	1.36	1.37	1.38	1.39	1.35	1.37	compacted
Sand	27.00	29.00	30.00	30.00	29.00	29.00	
Clay	38.00	37.00	36.00	34.00	38.00	36.60	
Silt	35.00	34.00	34.00	36.00	33.00	34.40	
Textural class	clay loam	Clay Loam	clay loam	clay loam	Clay loam	clay loam	

CEC = cation exchange capacity; P = phosphorus; K = potassium; ppm = part per million; pH = potential of hydrogen

Following the standardizations of Murphy (1968), soils with pH (5.19) and organic carbon (1.26%) were categorized as strongly acidic and low

in standards, respectively. Similarly, soil with 0.12% nitrogen, 8.64 ppm phosphorus and 0.678 cmol (+) kg⁻¹ of soil potassium concentrations

was categorized as low and the cation exchange capacity (15.64 cmol (+) kg⁻¹ of soil) was moderate.

Experimental Treatments and Design

The treatment set up for an experiment varied from year to year to estimate the change in potato tuber yield of each year. Thus, in the first year, potato was planted with four different level of organic treatments (V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM +2.5 t/ha FSB) in a completely randomized block design (RCBD) with four replications. In the second year, four level organic treatments (V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM +2.5 t/ha FSB) were factorially combined with two rotation systems (R1 = wheat undersowing lupine in the first year and potato under sown lupine in the second year, and R2 = lupine in the first year and potato under sown lupine in the second year) in a completely randomized block design (RCBD) with four replications. In the third year again, the organic treatments (V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM +2.5 t/ha FSB) were factorially combined with the two rotation systems (R3 = wheat under sown lupine in the first year, clover in the second year and potato in the third year, and R4 = clover in the first year, wheat under sown lupine in the second

year and potato in the third year) in a completely randomized block design (RCBD) with four replications.

The gross size of the experimental plots was 3x3 m (9 m²) with net harvesting plot area of 2.6x2.6 m (6.76 m²). Adjacent plots within replications were separated with 0.5 m wide paths, while the spacing between adjacent replications was 1m. Sesbania branches and leaves were cut and chopped before incorporated into the soil. As per the treatments and the design, fresh Sesbania green manure and farmyard manure were uniformly broadcasted on the surface of the plots and incorporated immediately within 20 cm soil depth two weeks before planting. Clover as well as under sown lupine in wheat and potato plots were also chopped and incorporated into the soil at their 50% flowering growth stages. Seed tubers of recently released potato variety “Belete” were used with recommended inter-row and intra-row spacing of 70 cm x 30 cm, respectively.

Farmyard manure was produced with mixtures of fresh cow dung (55%), sheep (35%), chicken waste (5%) and *tree lucerne* as bedding material (5%). After maturation, the organic manure was analyzed for the nutrient concentration by collecting composite samples at top, middle and base of the pit and the results are presented in Table 2.

Table 2: Chemical contents of different manure sources used for the study

Manure source	pH (H ₂ O)	CEC	OC%	OM%	N%	P%	K%
Farmyard manure	7.44	44.2	16.31	28.12	1.20	0.65	1.1
Sesbania (<i>Sesbania sesban</i>)					2.42	0.32	0.91
Lupine (<i>Lupinus albus</i>)					1.95	0.31	0.88
Clover (<i>Trifolium decoriom</i>)					2.17	0.43	0.89

p^H = potential of hydrogen; CEC = cation exchange capacity; OC = organic carbon; OM = organic matter; N = nitrogen; P = phosphorus; K = potassium

Data Collection and Analysis

Data of marketable, unmarketable and total tuber yields of potato were collected following their respective standard methods and procedures. The data were further subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures of SAS version 9.1 (SAS, 2002). For parameters whose ANOVA results showed significant differences between treatments, mean separation was done using least significant difference (LSD) test at their respective level of error used for analysis of variance.

RESULTS AND DISCUSSION

Potato Yield Trend

Potato tuber yield was varied significantly ($P < 0.01$) in response to the main effects of organic treatments (M) and crop rotation systems (T) as well as their interaction (M x T) in each site and in combined over sites from 2013-2015.

The variation in level of organic treatments were significantly ($P < 0.05$) affected potato tuber yield in 2013 (Table 3). The highest marketable and total potato tuber yield were recorded at 5 t/ha FYM +2.5 t/ha FSM at both sites and in combined over sites. The marketable tuber yield (14.32 t/ha) recorded was maximum at on-station plots. Similar to the on-station, the marketable yield 14.09 t/ha and 14.20 t/ha was also the maximum at on-farm conditions and in combined over the sites, respectively. The tuber yield in the station is a bit higher than that of on-farm condition due to the variation in initial soil conditions (Table 1). In addition, the total tuber yield of potato increased with the same scenario on the marketable yield of

potato. FYM at 5 t/ha+2.5 t/ha FSM showed the highest total potato tuber yield (14.69 t/ha) at on-station. Similarly, the total tuber yields of 14.49 and 14.59 t/ha were also superior at on-farm and in combined over sites, respectively. Following this treatment, FYM at 5 t/ha showed better potato tuber yield with 11.32 t/ha at on-station; 13.49 t/ha at on-farm and 12.04 t/ha in combined over sites. The unfertilized control showed the minimum total potato tuber yield of 4.26, 6.71 and 5.49 t/ha at the station, on-farm and in combined over sites, respectively. The total tuber yield at a combination of manure increased by 165% compared to that of the unfertilized control.

The increase in potato tuber yield at 5 t/ha FYM +2.5 t/ha FSM was due to the availability of more concentration of soil nutrients at the maximum level of organic treatments. The combination of manure contained the greatest quantity of 121, 40.5 & 73 t/ha of NPK, respectively, of soil nutrients compared to the lower levels (Appendix 1). The lowest yield on unfertilized control showed that the initial soil conditions were poorer to achieve modest potato tuber yield in Gusha soil conditions (Table 1).

Similarly, the increasing level of organics treatments and crop residue measurably increases the marketable and total tuber yield of potato in 2014 (Table 3). Thus, application of 5 t/ha FYM +2.5 t/ha FSM resulted in the highest marketable tuber yield of 22.4, 24.4 and 23.36 t/ha at the station, on farm and in combined over sites, respectively. Like ways, the highest total potato tuber yields of 23.5 t/ha at station; 25.5 t/ha at on-farm and 24.52 t/ha in combined over sites were recorded at 5 t/ha of FYM + 2.5 t/ha FSB. Following this treatment, FYM at 5 t/ha with 60, 33 & 50 t/ha of NPK, respectively, showed greater

total potato tuber yield of 22.60 t/ha at station; 23.30 t/ha at on-farm and 22.92 t/ha in combined over sites. The unfertilized control showed the lowest total tuber yield of 11.2, 10.4 and 10.8 t/ha potatoes at station, on-farm and in combined over sites, respectively.

Furthermore, the variation in levels of organic treatments significantly ($P < 0.05$) affected the tuber yield of potato at both sites and in combined over sites in 2015. Farmyard manure at 5 t/ha + 2.5 t/ha of FSB demonstrated the highest marketable tuber yield (29.52 t/ha) at the station. Similarly, the marketable yield (29.64 t/ha) was the greatest at on-farm conditions. The marketable yield (29.57 t/ha) recorded was also highest in combined over sites compared to other treatments in previous year. The trends of total potato tuber yields were similar to the marketable yield of potato. Total potato tuber yield of 31.43 t/ha was the largest at the station. In the same way, the total tuber yield of 31.55 t/ha was the biggest at the on-farm condition. Similarly, total tuber yield of 31.49 t/ha was the greatest in combined over sites. However, the unfertilized control showed the minimum marketable tuber yields of 11.9, 12.16 and 12.01 t/ha at the station, on-farm and in combined over sites, respectively.

In general, the total tuber yields of potato were the highest at the highest level of organic treatments and the lowest at the lowest level of organic treatments. This was because of the availability of high amount of soil nutrients from the combination manure. The combination of manure at 5 t/ha FYM + 2.5 t/ha FSM contains the maximum amount of soil nutrients with 121, 40.5 & 73 t/ha of NPK, respectively, than other treatments (Appendix 2). Several research reports supported the importance of organic fertilizer in replenishing

the degraded soil in potato yield. According to Swadija (2013) the highest total tuber yield of 23.49 t/ha was obtained from 6.5 t/ha of FYM compared to the lowest level. Similarly, Amir *et al.* (2012) argue that the tuber yield of potato was increased by increasing the level of FYM, but supplement above 20.9 t/ha did not increase the tuber yield. This is also supported by Najm *et al.* (2013) who showed that potato tuber yields of 20 t/ha were the highest at 15 t/ha of FYM than its lower level. Amber *et al.* (2011) also showed the yield attributing characters of potato were significantly augmented by annual application of organic treatments and showed the highest increase at higher rate of organic fertilizer compared to unfertilized control. Furthermore, Amir *et al.* (2006) also suggested that maximum tuber yield of 35.34 t/ha was recorded at maximum rates of farmyard manure (20 t/ha) whereas amounts of tuber yields of 25 t/ha were the minimum at the lower rate of FYM at 5 t/ha. Consistent with this suggestion, Stefano *et al.* (2010) confirmed that potato preceded by clover showed 35% yield increase than winter wheat.

Unlike the main effect of organic treatment, crop rotation system (T) did not bring about significant ($P < 0.05$) difference on the marketable and total yield of potato in 2014 (Table 4). However, relatively greater total yield of potato (18.8 t/ha) was recorded when potato was followed by sole lupine at on-station. In the same way, the total tuber yield of potato was the highest with 18.9 and 18.85 t/ha at on-farm and in combined over sites, respectively. However, the rotation system of potato followed by wheat undersowing lupine showed the lowest total tuber yield of 18.2, 18.8 and 18.55 t/ha at the station, on farm and in combined over sites, respectively. A similar scenario was recorded on the unmarketable

Table 3: Main effects of organic treatments on potato tuber yields over sites and years in Gusha Shinkurta rural village, Awizone, Northwest Ethiopia

Year	Organic treatments	On-station				On-farm				Over sites combination			
		MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)
2013	V1	3.64 ^d	0.63 ^a	4.26 ^c	6.14 ^c	0.58	6.71 ^c	4.89 ^d	0.60 ^a	5.49 ^d			
	V2	6.59 ^{cd}	0.15 ^d	6.74 ^c	10.34 ^b	0.50	10.84 ^b	8.47 ^c	0.32 ^c	8.79 ^c			
	V3	10.97 ^b	0.35 ^c	11.32 ^b	13.01 ^a	0.48	13.49 ^a	11.98 ^b	0.41 ^{bc}	12.40 ^b			
	V4	14.32 ^a	0.38 ^c	14.69 ^a	14.09 ^a	0.40	14.49 ^a	14.20 ^a	0.39 ^{bc}	14.59 ^a			
	Sig. difference	**	**	**	**	ns	**	**	**	**	**	**	
2014	V1	9.60 ^c	1.60 ^a	11.20 ^c	8.60 ^c	1.76 ^a	10.4 ^d	9.11 ^d	1.69 ^{ab}	10.8 ^d			
	V2	14.90 ^b	1.80 ^a	16.70 ^b	14.50 ^c	1.86 ^a	16.4 ^c	14.71 ^c	1.83 ^a	16.5 ^c			
	V3	21.10 ^a	1.50 ^b	22.60 ^a	21.60 ^b	1.73 ^a	23.3 ^b	21.30 ^b	1.61 ^b	22.92 ^b			
	V4	22.40 ^a	1.20 ^c	23.50 ^a	24.40 ^a	1.15 ^b	25.5 ^a	23.36 ^a	1.16 ^c	24.52 ^a			
	Sig. difference	*	**	**	*	**	*	**	**	**	**	**	
2015	V1	11.9 ^d	2.18 ^a	14.08 ^c	12.16 ^d	2.13 ^a	14.27 ^d	12.01 ^d	2.14 ^a	14.18 ^d			
	V2	17.66 ^c	1.96 ^{ab}	19.70 ^c	15.82 ^c	2.02 ^{ab}	17.85 ^c	16.73 ^c	2.01 ^b	18.77 ^c			
	V3	23.44 ^b	2.03 ^b	25.41 ^b	22.46 ^a	2.01 ^{ab}	24.47 ^b	22.95 ^b	1.96 ^{bc}	24.94 ^b			
	V4	29.52 ^a	1.91 ^b	31.43 ^a	29.64 ^a	1.90 ^b	31.55 ^a	29.57 ^a	1.90 ^c	31.49 ^a			
	Sig. difference	*	**	*	*	*	**	**	*	**	*	*	

V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM +2.5 t/ha FSB; MTY= marketable tuber yield; UMTY= unmarketable tuber yield; TTY = Total tuber yield; ns = non significant; ** = highly significant at $P<0.01$; * = significant at $P<0.05$.

yield of potato (Table 4). Potato followed by sole lupine showed the highest total tuber yield at both sites and in combined over sites. Lack of significant change between two rotation systems was observed because the influence of the rotation

system was minimal to bring significant change on tuber yields of potato (Table 4). Lupine both in undersowing and in sole cropping system gave an equivalent size of biomass to influence the succeeding crop similarly.

Table 4: Main effects of crop rotation on potato tuber yields over sites and years in Gusha Shinkurta rural village, Awi Zone, Northwest Ethiopia

Year	Crop rotation system	On-station			On-farm			Over sites combination		
		MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)
2014	R1	16.69	1.52	18.2	17.28	1.60	18.80	17.00	1.56	18.55
	R2	17.27	1.53	18.8	17.25	1.65	18.90	17.26	1.59	18.85
	Sig. difference	ns	ns	ns	ns	ns	ns	ns	ns	ns
2015	R3	22.00 ^a	2.03	24.02 ^a	21.81 ^a	2.04	23.81 ^a	21.9 ^a	2.00 ^a	23.91 ^a
	R4	19.25 ^b	2.01	21.29 ^b	18.21 ^b	1.99	20.26 ^b	18.73 ^b	2.04 ^a	20.77 ^b
	Sig. difference	*	ns	**	*	ns	**	*	ns	*

R1= wheat undersowing lupine-potato; R2 = lupine-potato, R3 = wheat-clover-potato; R4 = clover-wheat under sown lupine-potato; MTY= marketable tuber yield; UMTY= unmarketable tuber yield; TTY = Total tuber yield; ns = non significant; ** = highly significant at $P<0.01$; * = significant at $P<0.05$.

However, crop rotation system (T) resulted in significant ($P<0.01$) difference on tuber yield of potato in 2015 (Table 4). Potato followed by clover and wheat showed the highest marketable and total potato tuber yield than potato followed by wheat under sown lupine and clover. At the station, the maximum marketable potato tuber yield (22 t/ha) was recorded when potato was followed by clover and wheat. Similarly, the marketable yield (21.81 t/ha) recorded at R3 was maximum at on-farm conditions. Tuber yield in combined over

sites showed similar trends as the individual sites where the marketable yield (21.81 t/ha) was higher than other treatments. However, the lowest marketable yields of 19.25 18.21 and 18.73 t/ha were recorded when potato was followed by wheat under sown lupine and clover (R1) at the station, on-farm and in combined over sites, respectively. Similar scenario was observed on total tuber yield of potato. Potato followed by clover and wheat rotation system showed the highest total potato tuber yields of 24.02, 23.81 and 23.91 t/ha at

station, on-farm and in combined over location, respectively. However, potato followed by wheat under sown lupine and clover (R1) showed the lowest total tuber yields of 21.29, 20.26 and 20.77 t/ha at station, on-farm and in combined over sites, respectively. The results indicate that planting of green manure crops especially clover as preceding crop enhances soil nutrients and improves potato yield tremendously. This is in agreement with the research results of Malihe *et al.* (2015) who reported that green manure as preceding crop improved the tuber yield of potato by improving the fertility and ameliorating soil physical properties. Similarly, Eugenija *et al.* (2014) reported that maximum tuber yield of potato was obtained after clover than barley rotation system. Malihe *et al.* (2015) also found that potato plants grown in plots following common vetch and faba bean produced 12.7% and 15.0% more tuber yield, respectively, compared with that of winter wheat. Similarly, Stefano *et al.* (2010) indicated that clover green manure and farmyard manure substantially increased the total yield by 22.5% and 25.1%, respectively, over the untreated control. Similarly, Sanderson and Macleod (1993) reported that tuber yields were lower following barley than following lupine green manure.

Like the main effects of organic treatment (M), the interaction (M x T) effect of organic treatment and crop rotation system showed significant ($P < 0.001$) difference on tuber yields of potato in 2014 and 2015 (Table 5). The highest marketable and total tuber yield of potato was recorded at the interaction effects of 5 t/ha of FYM + 2.5 t/ha FSB and potato followed by sole lupine (R2V4) compared to all other treatment combinations in 2014. Thus, the total tuber yields of 24.2, 25.4 and 24.8 t/ha at on-station, on-farm and in combined over locations, respectively, were the highest

by any standards compared to other treatment combinations. Marketable yield also showed similar trend to the total yield of potato (Table 5). However, the interaction of unfertilized control and wheat under sown lupine showed the smallest tuber yield in both sites and in combined over sites. The total tuber yields of 10, 11 and 10.5 t/ha at station, on-farm and in combined over location, respectively, were lower by any standards. In general, an increase in potato tuber yield due to variation in cropping system and rate of manure indicated that soil nutrients were improved by the system of soil fertilization. This was because of the availability of the highest amount of soil nutrients from the interaction of 5 t/ha of FYM + 2.5 t/ha FSB and due to the fact that potato was followed by sole lupine with superior quantity of 179, 50.3 & 99.4 kg/ha of NPK, respectively, than other treatments (Appendix2).

In addition, the interaction (M x T) effects of organic treatment and crop rotation system showed significant ($p < 0.001$) difference on tuber yield of potato in 2015 (Table 5). Maximum marketable and total tuber yield were recorded at the highest levels of organic treatment and sound crop rotation system, and become the minimum on unfertilized control and less sound rotation systems. The highest marketable potato yield (32.5 t/ha) was recorded at the interaction effects of 5 t/ha FYM + 2.5 t/ha FSM and potato followed by clover and wheat at the station. Incoherent with the station, marketable yield (34.02 t/ha) was also highest at on-farm conditions. Similarly, the marketable yield (33.28 t/ha) was the peak in combined over sites. Following this treatment, the interaction effects of 5 t/ha FYM + 2.5 t/ha FSM and potato followed by wheat undersowing lupine and clover showed the highest marketable yield of 26.5, 25.28 and 25.88 t/ha at the station, on farm and

Table 5: Interaction effects of organic treatments and crop rotation on potato tuber yields over sites in Gusha Shinkurta rural village, Awi Zone, Northwest Ethiopia

Year	Crop rotation system	Organic Treatment	On-station				On-farm				Over sites combination			
			MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)
2014	R1	V1	9.40 ^c	1.60 ^a	11.00 ^c	8.20 ^d	1.60 ^a	10.00 ^d	8.80 ^d	1.60 ^{ab}	10.50 ^d	8.80 ^d	1.60 ^{ab}	10.50 ^d
		V2	14.80 ^b	1.90 ^a	16.60 ^b	14.60 ^c	1.80 ^a	16.40 ^c	14.72 ^c	1.80 ^a	16.50 ^c	14.72 ^c	1.80 ^a	16.50 ^c
		V3	20.80 ^a	1.40 ^{ab}	22.30 ^a	21.80 ^b	1.40 ^{ab}	23.40 ^b	21.40 ^b	1.50 ^b	22.80 ^b	21.40 ^b	1.50 ^b	22.80 ^b
		V4	21.60 ^a	1.40 ^b	22.90 ^a	24.40 ^a	1.20 ^b	25.50 ^a	23.00 ^a	1.17 ^c	24.20 ^{ab}	23.00 ^a	1.17 ^c	24.20 ^{ab}
	R2	V1	9.70 ^c	1.60 ^a	11.40 ^c	8.90 ^d	1.70 ^a	10.70 ^d	9.30 ^d	1.70 ^{ab}	11.00 ^d	9.30 ^d	1.70 ^{ab}	11.00 ^d
		V2	15.00 ^b	1.70 ^a	16.80 ^b	14.40 ^c	1.80 ^a	16.30 ^c	14.70 ^c	1.80 ^a	16.55 ^c	14.70 ^c	1.80 ^a	16.55 ^c
		V3	21.20 ^a	1.50 ^{ab}	22.80 ^a	21.30 ^b	1.50 ^a	23.10 ^b	21.30 ^b	1.60 ^{ab}	22.90 ^b	21.30 ^b	1.60 ^{ab}	22.90 ^b
		V4	23.00 ^a	1.10 ^b	24.20 ^a	24.30 ^a	1.10 ^b	25.40 ^a	23.60 ^a	1.15 ^c	24.80 ^a	23.60 ^a	1.15 ^c	24.80 ^a
Sig. difference			**	**	**	**	*	**	*	**	*	**	**	
SE (d) ±			1.18	0.18	1.22	0.89	0.14	0.92	1.07	0.16	1.12	1.07	0.16	1.12
CV (%)			9.80	16.70	9.30	7.30	12.30	6.90	9.10	14.7	9.60	9.10	14.7	9.60
2015	R3	V1	12.7e	2.16 ^a	15.07 ^f	13.50 ^g	2.06 ^{ab}	15.60 ^g	13.2 ^g	2.12 ^{ab}	15.31 ^e	13.2 ^g	2.12 ^{ab}	15.31 ^e
		V2	18.67 ^d	2.02 ^a	20.70 ^d	16.55 ^e	1.97 ^{abc}	18.52 ^e	17.61 ^e	2.04 ^{abc}	19.61 ^d	17.61 ^e	2.04 ^{abc}	19.61 ^d
		V3	23.92 ^{bc}	1.95 ^{bc}	25.87 ^c	23.19 ^c	2.02 ^{abc}	25.22 ^c	23.55 ^c	1.98 ^{abc}	25.53 ^c	23.55 ^c	1.98 ^{abc}	25.53 ^c
		V4	32.54 ^a	1.90 ^c	34.45 ^a	34.02 ^a	1.87 ^c	35.90 ^a	33.28 ^a	1.87 ^c	35.15 ^a	33.28 ^a	1.87 ^c	35.15 ^a
	R4	V1	10.90 ^e	2.20 ^a	13.10 ^g	10.77 ^h	2.14 ^{ab}	12.95 ^h	10.83 ^h	2.17 ^a	13.02 ^f	10.83 ^h	2.17 ^a	13.02 ^f
		V2	16.64 ^d	2.05 ^{abc}	18.70 ^e	15.09 ^f	2.07 ^{abc}	17.17 ^f	15.87 ^f	1.96 ^{abc}	17.92 ^d	15.87 ^f	1.96 ^{abc}	17.92 ^d
		V3	22.97 ^c	1.97 ^{bc}	24.95 ^c	21.72 ^d	2.00 ^{abc}	23.72 ^d	22.34 ^d	1.98 ^{abc}	24.32 ^c	22.34 ^d	1.98 ^{abc}	24.32 ^c
		V4	26.5 ^b	1.92 ^{bc}	28.42 ^b	25.28 ^b	1.93 ^{bc}	27.17 ^b	25.88 ^b	1.91 ^{bc}	27.81 ^b	25.88 ^b	1.91 ^{bc}	27.81 ^b
Sig. difference			ns	**	**	*	**	**	*	**	*	**	*	
SE (d) ±			0.09	0.76	0.80	0.09	0.53	0.51	0.10	0.52	0.10	0.36	0.52	
CV (%)			6.73	9.46	5.00	6.38	6.95	3.44	6.76	5.73	7.02	6.76	5.73	7.02

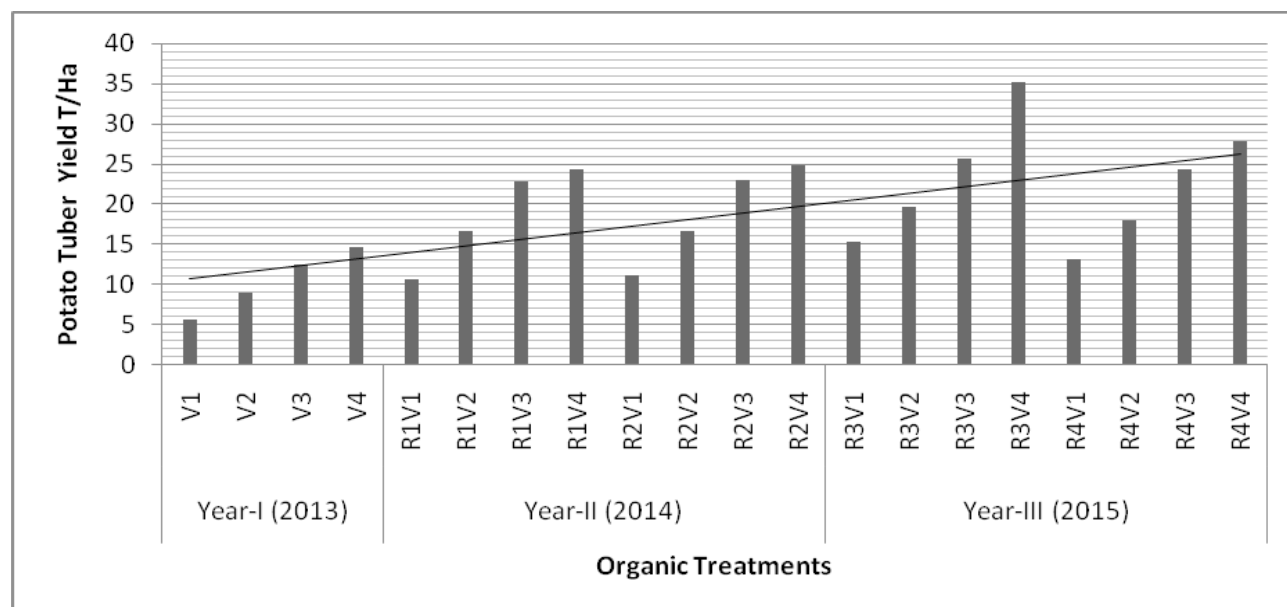
R1= wheat undersowing lupine-potato; R2 = lupine-potato, R3 = wheat- clover- potato; R4 = clover-wheat under sown lupine- potato; V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM +2.5 t/ha FSB, MTY = marketable tuber yield; UMTY = unmarketable tuber yield; TTY = Total tuber yield; ns = non significant; ** = highly significant at $P < 0.01$; * = significant at $P < 0.05$.

in combined over sites, respectively. However, minimum marketable tuber yield was recorded on the interaction effects of unfertilized control and potato followed by wheat under sown lupine and clover rotation system (Table 5). The total tuber yield of potato also varied with the same trend to the marketable yield of potato. Total tuber yield of potato was highest at the highest levels of organic treatment and sound rotation system but was lowest at the lowest levels organic treatment and less sound rotation system. Thus, the highest total potato tuber yield (34.45 t/ha) was recorded at the interaction effects of 5 t/ha FYM + 2.5 t/ha FSM and potato followed by clover and wheat (R3V4) in the station. In the same way, the total tuber yield (35.90 t/ha) recorded was maximum at on-farm conditions. The combined over sites still showed the highest total tuber yield (35.15 t/ha) compared to other treatment combinations. Following the above treatment, the interaction effects of 5 t/ha FYM + 2.5 t/ha of FSM and potato followed by clover and wheat (R4V4) showed greater total potato tuber yield next to R3V4. The total tuber yields were 28.42, 27.17 and 27.81 t/ha at the station, on-farm and in combined over sites, respectively. However, the interaction effects of unfertilized control and potato followed by wheat under sown lupine and clover (R2V1) rotation systems showed the lowest total tuber yield of 13.1, 12.95 and 13.02 t/ha at the station, on-farm and in combined over sites, respectively. The harvesting of the highest yield at the higher rate of organic treatment and potato immediately followed by clover enriched the soil with nitrogen and other nutrients to fulfill the nutrient demand of the crop (Appendix 3).

In general, the yield of potato showed increasing trends in response to organic treatments and crop rotation system year after year (Figure 3). Tuber yields of potatoes were the lowest in the

first year, intermediate in the second and hit the highest in the third year across each treatment. For example, the maximum level of organic treatment that showed the highest potato tuber yield across all years produced the lowest potato tuber yield (14.59 t/ha) in the first year, an intermediate potato tuber yield (24.8 t/ha) when preceded by sole lupine in the second year and showed maximum potato tuber yield (35.15 t/ha) when integrated with potato followed by clover and wheat rotation system in the third year. The yield advantage of the third season increased by 140% and 41% compared with the yield of potato in the first and the second year, respectively.

The appreciable increasing trend of potato yield over the three years could arguably be generalized due to the carryover effects of the annual application of organic inputs and residue from rotation system. This result is in line with Manoj *et al.* (2013) who reported that long-term organic treatment either from the preceding crop or FYM improves steadily potato yield over the years with the lowest at the beginning of project phase and the highest at the end of the fifth year. Similarly, Fan *et al.* (2005) showed that long-term additions of organic materials definitely arrested potato yield declines and improved yield year after year. Furthermore, Amber *et al.* (2010) reported that tuber yield of potato significantly increased year after year through applications of composted dairy manure and proper rotation system. Comparable yield trend was also observed in ranges of field crops including wheat. Mando *et al.* (2005) demonstrated that greater grain and straw yields of wheat were recorded on long-term manure input than on the unfertilized control. Similarly, Hatch *et al.* (2008) in their long-term study demonstrated that maize straw and grain yield showed the largest increase at the end of long term manure fertilization.



V1= 0 t/ha FYM; V2 =2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM +2.5 t/ha FSB; R1= wheat undersowing lupine-potato; R2 = lupine-potato, R3 = wheat-clover-potato; R4 = clover-wheat under sown lupine-potato

Figure 3: The tuber yield trend of potato (t/ha) in response to organic treatments and rotation system from 2013 to 2015

CONCLUSIONS

The variation in level of organic manure and crop rotation system and their interaction effects showed the strongest influence on tuber yield of potato. Application of different levels of organic treatments influenced the yield of potato differently. Potato tuber yield was the highest at the maximum level of organic treatments and the smallest at the lowest level of organic treatments. Similarly, growing green manures as a preceding crop substantially improved the yield of potato. Potato tuber yield was greater when the potato was immediately followed by clover and sole lupine than undersowing forms. In addition, the interaction effects of a combination of manure and sound crop rotation system synergistically

improved the tuber yield of potato. Maximum potato tuber yield was recorded at interaction effects of 5 t/ha FYM +2.5 t/ha FSB and when potato was followed by clover and wheat compared to other treatments combinations. This was certainly due to a high level of soil nutrient replenishing rate at the maximum level of organic treatments and sound rotation system on the longest term of rotation. Hence, it could be concluded that even though separate application of organic treatment and rotation system has a positive effect on yield performance of potato, their combined use has more beneficial effect in improving potato yield. Finally, selection of different types of green manure that better fit with the agro-ecosystem of the district could be an intervention in the future.

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APPENDIXES

Appendix 1: Nutrient levels applied in the form of manure in 2013

Treatment	Manure (t/ha)			Nutrient content (kg/ha)		
	N	P	K	N	P	K
0 t/ha FYM (V1)	0.00	0.00	0.00	0.00	0.00	0.00
2.5 t/ha FSB (V2)	2.50	60.50	23.00	60.50	8.00	23.00
5 t/ha FYM (V3)	5.00	60.00	50.00	60.00	32.50	50.00
5 t/ha FYM +2.5 t/ha FSB (V4)	7.50	121.00	73.00	121.00	40.50	73.00

FYM= farmyard manure; FSB = fresh sesbania biomass; N = nitrogen; P = Phosphorus; K = potassium

Appendix 2: Nutrient levels applied in the form of manure in 2014

TRT	LB (t/ha)	Nutrient from LB (kg/ha)			FYM (t/ha)	Nutrient from FYM (kg/ha)			Total nutrient Received (kg/ha)		
		N	P	K		N	P	K	N	P	K
R1V1	3.00	58.50	9.30	26.40	0.00	0.00	0.00	58.50	9.30	26.40	
R1V2	3.00	58.50	9.30	26.40	2.50	60.50	23.00	119.00	17.30	49.40	
R1V3	3.00	58.50	9.30	26.40	5.00	60.00	50.00	118.50	42.30	76.40	
R1V4	3.00	58.50	9.30	26.40	7.50	120.5	73.00	179.00	50.30	99.40	
R2V1	3.00	58.50	9.30	26.40	0.00	0.00	0.00	58.50	9.30	26.40	
R2V2	3.00	58.50	9.30	26.40	2.50	60.50	23.00	119.00	17.30	49.40	
R2V3	3.00	58.50	9.30	26.40	5.00	60.00	50.00	118.50	42.30	76.40	
R2V4	3.00	58.50	9.30	26.40	7.50	120.50	73.00	179.00	50.30	99.40	

TRT = treatment; V1= 0 t/ha FYM; V2 = 5 t/ha FYM; V3 = 2.5 t/ha FSB and V4 = 5 t/ha FYM +2.5 t/ha FSB; R1= Wheat US lupine; R2= lupine; LB = lupine biomass; N = nitrogen; P = Phosphorus and K = potassium.

Appendix 3: Nutrient levels applied in the form of manure in 2015

TRT	Green Manure (t/ha)	Nutrient from LB/CB			FYM (t/ha)	Nutrient from FYM			Sum of all nutrients (kg/ha)		
		N	P	K		N	P	K	N	P	K
R3V1	0.00	2.90	12.47	25.81	0.00	0.00	0.00	62.93	12.40	25.81	
R3V2	0.00	3.40	14.62	30.26	2.50	60.50	8.00	134.208	22.62	53.26	
R3V3	0.00	4.70	20.21	41.83	5.00	60.00	32.50	161.99	52.71	91.83	
R3V4	0.00	5.40	23.22	48.06	7.50	121.00	40.50	238.18	63.72	121.01	
R4V1	0.79	0.00	2.449	6.95	0.00	0.00	0.00	15.40	2.44	6.952	
R4V2	0.85	0.00	2.635	7.48	2.50	60.50	8.00	77.07	10.63	30.48	
R4V3	1.15	0.00	3.565	10.12	5.00	60.00	32.50	82.42	36.06	60.12	
R4V4	1.29	0.00	3.999	11.352	7.50	121.00	40.50	146.15	44.49	84.35	

TRT = treatment; V1= 0 t/ha FYM; V2 = 5 t/ha FYM; V3 = 2.5 t/ha FSB and V4 = 5 t/ha FYM +2.5 t/ha FSB; R3 = wheat-clover-potato; R4 = clover-wheat under sown lupine-potato; LB = lupine biomass; CB = clover biomass; FYM = farmyard manure; N = nitrogen; P = Phosphorus; K = potassium