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Comparison of bioslurry to common nitrogen sources on potato (*Solanum tuberosum* L.) yield and yield components in andisols and oxisols of Northern Rwanda

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This study evaluated the effect of bioslurry from on-farm biogas production units and other sources of nitrogen fertilizer on Irish potato yield and yield components in northern Rwanda. To achieve this, an on-farm experiment was undertaken in the Andisols of Musanze District and the Oxisols of Gicumbi District in 2012. Three farms were selected to host the study in each District. Six treatments were randomly tested in unreplicated field strips by farm, one treatment by strip. The treatments comprised of i_1) a control with no fertilizer (CTL000); i_2) a control supplying 100% of recommended N rate from chemical fertilizers (MIN100); i_3) a treatment supplying 100% of recommended N rate from farm yard manure (FYM100); i_4) a treatment supplying 40% of recommended N amount from bioslurry and 60% from mineral N fertilizer (BIO040); i_5) a treatment supplying 60% of recommended N amount from bioslurry and 40% from mineral N fertilizer (BIO060); and i_6) a treatement supplying 100% of recommended N amount from bioslurry (BIO100). The results indicated that locally produced bioslurry appeared very low-nitrogen concentrated and for some farms, more than 100 m^3 /ha of bioslurry was needed to meet potato nitrogen requirements. Bioslurry appeared as effective as or better than conventional nitrogen sources to improve soil properties such as soil pH and organic matter content, and to sustain potato growth and tuber yield and quality. This was particularly true when bioslurry was combined with mineral fertilizer. In that regard, bioslurry can contribute between 40 and 60% reduction of mineral fertilizers with no subsequent reduction of market or total potato tuber yields.

Key words: Bioslurry, organic fertilizer, mineral fertilizer, organic sources, soil quality, potato yield.

INTRODUCTION

Bioslurry is a biowaste product from biogas generation units that have been promoted in Rwanda to produce energy in replacement of wood charchoal and firewood. Bioslurry offers the potential of both a rich source of nutrients and an amendment for Rwandan soils. It contains appreciable amounts of organic matter (20 to 30%) very much needed for soil quality improvement (Droogers and Bouma, 1996); it is environmentally friendly (Kumar et al., 2015) and has no toxic or harmful effects on the soil (Islam, 2006). Moreover, bioslurry contains higher concentrations of plant N, P, and K nutrients that are more readily available to crops (Warnars and Oppenoorth, 2014) than farmyard manure and compost. The use of bioslurry could reduce at least 40-50% of chemical fertilizer applications (Islam, 2006) while accelerating organic N mineralization because of its low organic C: N ratio (Warnars and Oppenoorth, 2014).

In Rwanda, long-term land exploitation for agriculture and subsequent water erosion have depleted Rwandan soils in fine particles (Karamage et al., 2016) and organic matter (Mbonigaba et al., 2009). As a result, the application of organic biomass as soil amendments and plant nutrient sources has become a common practice of the crop production intensification program the country has been promoting for adoption by small farmers (Rushemuka et al*.,* 2014). These applications are generally supplemented with mineral sources of plant nutrients.

In terms of efficiency as a source of plant nutrients, several studies reported bioslurry as a good compound fertilizer, which can reduce the application of expensive chemical fertilizers (Haque et al., 2015; Shahbaz et al*.,* 2014). In that regard, bioslury application resulted in yield increases of 30.9, 56.9 and 30.4% for potato tubers, corn, and rice, respectively (Gurung, 1997) while the application of bio-slurry in combination with mineral fertilizers resulted in a 25 to 36% increase of Okra fruit yields in comparison with mineral fertilizer applications alone (Shahbaz et al., 2014). Also, the application of 7.8 tons /ha of bioslurry on carrots increased yields by 8.8% and 23.5% compared to the control over two consecutive seasons (Jeptoo et al*.,* 2013). This high efficacy of bioslurry when combined with mineral fertilizers was also reported in other research findings (Hossain et al. 2014).

Therefore, this study aimed at: i) assessing the efficacy of bioslurry from on-farm biogas production plants as a soil amendment and potato N nutrient source in comparison with farm yard manure and mineral nitrogen fertilizer in two agro-ecological regions of northern Rwanda and, ii) determining the range of bioslurry fraction in its combinations with mineral fertilizer for optimum potato tuber yields in the same regions.

MATERIALS AND METHODS

Description of the study area

This study was carried out in the first rainy season of 2012 in Musanze and Gicumbi Districts respectively located Northwest and Northeast of Northern Province of Rwanda. Musanze is situated in the Northwest of the Northern Province, between 1,850m and 2,500m above sea level (asl) in the agro-ecological region of Birunga or Volcanos (Figure 1, n°4). A moderate and humid climate and abundant rainfalls characterize the region. The annual averages of temperatures and rainfalls are 16^{o}C and 1400 mm, respectively; the maxima annual rain precipitation averages around 1600 mm (Verdoodt and van Ranst, 2003). The soils of Musanze are mainly from volcanic materials and are classified in the Andisols. The experiment was done on three different farms located in Kinigi (2,150 m asl), Nyange (2,111 m asl), and Busogo (2,249 m asl), respectively.

The District of Gicumbi is located in northeast region of the Northern Province covering the natural region of the Buberuka Highlands (Figure 1, n° 6). Gicumbi has a tropical bimodal climate with rain precipitations ranging from 1,200 mm to 1,300 mm and mean temperatures ranging between 13.2 and 20.8°C. It is one of the most environmentally fragile regions of Rwanda characterized by rugged steep slope hills with narrow and wet valleys. The soils of Gicumbi are mainly degraded Oxisols characterized by lateritic materials (Verdoodt and van Ranst, 2003). However, local swamps and lowlands are characterized by rich and deep clay soils. The experiment was conducted on three farms located at Shangasha (2,166 m asl), Rukomo (mean altitude of 2,002 m asl) and Kageyo (2,167 m asl), respectively.

Treatments and application method

Treatments

Six treatments were tested on commonly grown Irish potato varieties, Kinigi variety in Musanze and Mabondo potato variety in Gicumbi. One farm field was selected in each one of the three administrative Sectors by District basing on the similarities of soil chemical characteristics. The selection was also based on the existence of a biogas production unit on the farm, the farmer's willingness to provide the land for the study and the gentle slope (5% slope or lower) of the provided land. The treatments were composed such that each (but the control) supplies potato nitrogen requirement in the amount of 150 kg N /ha (Zebarth et al., 2007) from different sources as follows:

1) Control (CTL000): No fertilizers applied on potato crop;
2) 150 kg N /ha all supplied from mineral fertilizers (MIN100) as follows: 60 kg /ha at planting and 90 kg /ha at hilling; in addition, phosphate and potash were band-applied at planting in the amounts of 15 0kg P_2O_5 /ha and 60 kg K_2O /ha, respectively;
3) 150 kg /ha were entirely supplied from farm yard manure (FYM100);
4) 150 kg N /ha required amount was supplied at 40% from bioslurry (BIO040) and the remaining 60% was supplied from mineral fertilizers;
5) 150 kg N /ha required amount was supplied at 60% from bioslurry (BIO060) and the remaining 40% was supplied from

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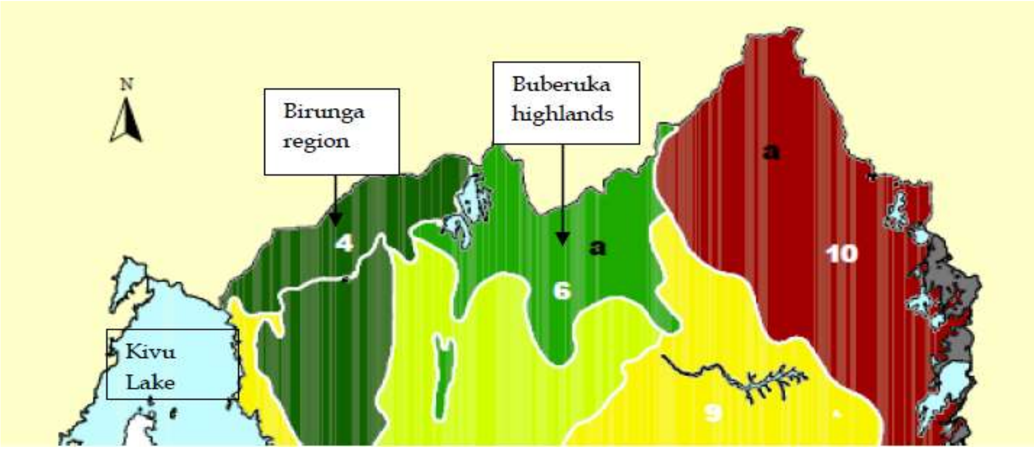

Figure 1. Location of the study area (in zones 4 and 6) in Northern Rwanda, particularly suitable for the potato production (adapted from Verdoodt and van Ranst, 2003).

mineral fertilizers;

6) 150 kg /ha of potato nitrogen fertilizer were all supplied from bio-slurry (BIO100); no mineral phosphate and potash fertilizers were added.

Experimental design and treatments′ application

At each site, the six treatments were randomly distributed and tested in un-replicated field strips, a treatment by strip. Each strip was at least 4m wide over the total length of the field. Chemical fertilizers were band-applied in a seed trench just before seeding and slightly covered by the soil to avoid direct contact of seed and fertilizer particles. Bioslurry application rates were calculated based on their actual N nutrient content to supply 150 kg N ha^{-1} to the potato crop. Farmyard manure was applied based on their N content from scientific literature (Sankaranarayanan and Karemangingo, 2012). No mineral P and K fertilizers were added to supplement these organic sources of nitrogen since they were supposed to supply required amounts of other nutrients, notably phosphorus and potassium nutrients. All organic manures were broadcast and incorporated before planting. For bioslurry treatments, which the balance was supplied from mineral N, this application was done at hilling time. Bioslurry application rates were adjusted based on a 50% nitrogen loss (Zebarth et al., 2007).

Potato seeds were sown at the spacing of 80cm between rows and 30 cm within rows. All seeds were medium size grade with a similar sprout status. Weeding operations were done two weeks after emergence and at hilling, 45 days after planting. Pests and diseases were controlled through regular field scounting and weekly applications of Dithane M45 to protect against the mildew. In Rukomo Sector, a combination of bacteria (Ralstonia solanacearum) and a fungii *(*Rhizoctonia *solanii)* caused severe damages to the crop. Harvesting was done about 120 days after planting.

Evaluation of the effects of treatments

Assessing bioslurry quality

Semi-liquid bioslurry samples were collected from the storage lagoons using a locally fabricated aluminum-made can with a spring-operated cup. A 2-m long handle fixed on the can was used to collect liquid samples from different depths and angles of the pit. Samples were collected after thoroughly mixing the sludge with wooden paddles. Composite samples made of single six samples were collected at 10 cm and 1 m depth from each farmer's pit. Each bioslurry sample was stored in 1L Nalgen bottles, kept in a cooler with icebags, taken to the laboratory, and kept frozen until analysis for nutrient contents.

Assessing the effects of N sources on soil quality

Before planting, a composite sample was taken from each farmer's field and tested for initial soil quality. After harvest, a composite sample was also taken from each field strip and tested to evaluate the treatment effect on the soil quality. In fact, soil samples were analyzed for pH in a 1: 2.5 soil-water solution (pH_{water}) using the glass electrode method, organic carbon (OC) using the Walkely and Black method, total nitrogen (total N) using the Kjeldahl method, total phosphorus (total P) using the vanado-molybdate method, available phosphorus using the Mehlich-3 method, potassium using the Na cobaltinitrite method, calcium (Ca) and magnesium (Mg) using the EDTA method, exchangeable aluminum (Al^{3+}) and total exchangeable acidity using titration method, and cation exchange capacity (CEC) using the ammonium acetate method.

Assessing the effects of N sources on potato growth, tuber yield and quality

The effects of treatments on the potato growth, yield and yield quality were performed on three sub-plots randomly selected by strip. Each sub-plot was 1.6m wide x 2.4m long or 3.84 m^2. The crop growth was estimated by measuring the plant length (cm) from the ground surface to the top of the plant using a measuring tape 30, 60, and 90 days after planting. The number of plants and shoots were counted at harvest. The potato tuber quality was assessed using a tuber calibration table which graded potato tubers into small size (< 5 cm circumference), medium size (5 to 10 cm), big size (10 to 15 cm) and very big size (> 15 cm circumference). The total weight obtained by summing up the weights of the potato tubers of all sizes, including rough and rot tubers represented the total potato tuber yield. The market potato tuber yield was the difference between the total potato tuber yield and the weights of small size tubers as well as rough and rot potato tubers.

Data statistical analyses

Data collected were organized using Excel data sheet. The one-way analysis of variance was performed District by District using the 4th Edition of NCSS computer package (Hintze, 2004). Data were eventually log-transformed when non-homogeneity of variance was detected with the Bartlett Chi-square test (Steel and Torie, 1980). Repeated measures analysis of variance was performed for parameters related to the plant growth. In all cases, Duncan's Multiple Range Test (DMRT) was perfomed for comparison of mean effects of treatments. A 5% probability level was used for the significance of all statistical analyses.

RESULTS AND DISCUSSION

On-fam generated bioslurry characteristics

Bioslurry characteristics as tested from different farms in Musanze and Gicumbi are presented in Table 1. These slurries appeared much less concentrated, particularly in N, P, and K nutrients than previously reported (Bonten et al., 2014; Sankaranarayanan and Karemangingo, 2012). Their quality is however variable from farm to farm as highlighted by the coefficients of variation. They are all in the ranges of those reported by Haque (2013) as well as Warnars and Oppenoorth (2014) for N, P, and K nutrients and by Kumar et al. (2015) for nitrogen, only.

This variability can be explained by the high variability of the quality of animal feeds, the method of loading biowaste into the biodigester and, at the end of the gas production process, the method of storing bioslurry. Biowaste loading into the biodigester is done by adding uncontrolled volume of water while, at the end of the process, the farmers reported frequent additions of soil into liquid bioslurry in the earthern lagoon to make it a biosolid easy for transport.

Effects of nitrogen sources on soil quality

Status of soil chemical properties prior to applying treatments

Prior to the application of treatments, the soil characteristics of the different sites are presented in Table 2. These soil properties are quite homogeneous across sites by District for each soil characteristic. They also indicate the differences that exist between Andisols and Oxisols, particularly with regard to soil pH, organic carbon, available phosphore, exchangeable Ca^{2+} cation, and CEC for which the Andisols contained higher values than the Oxisols while the opposite is true for exchangeable Al^{3+} and total acidity. The soils are classified from strongly-acid for Oxisols to weakly-acid for Andisols basing on their actual pH values as per Parent and Gagne (2010).

Consistent with their formation and chemical nature, Andisols are richer in Ca and organic matter than Oxisols (Hengel et al., 2017).

In these specific soils, the organic carbon varies from 1.6% to 2.4% in the Oxisols of Gicumbi and from 2.2% to 3.6% in the Andisols of Musanze, while the exchangeable calcium varies from 5.0 meq to 8.0 meq /100 g soil and from 11.8 meq to 13.8 meq /100 g soil in the two types of soils, respectively.

Status of soil chemical properties after treatments' application

The effects of different nitrogen sources on soil chemical properties as monitored immediately after harvest are here below presented in Table 3 for the parameters only offering significant differences in one or in both of the two soils. In general, the application of organic-based treatments, particularly the bioslurry ones, resulted in significantly higher values of assessed soil characteristics than CTL000 and MIN100 in the two soils. That is particularily true for soil organic matter, available phosphorus and cation exchange capacity.

Otherwise, a comparison between organic sources alone constantly indicates highest values from bioslurry-containing treatments. Therefore, organic-based treatments, particularly bioslurry-based treatments, contributed to significantly improving reported soil characteristics. These results are consistent with many previous findings on the improvement of soil chemical characteristics by organic materials (Kismanyoky and Toth, 2010; Rutunga et al., 1998; Mwanga, 2016).

Effects of nitrogen sources on potato growth, yields and yield components

Effects on the potato plant growth rate

The mean rate of potato plant growth as measured by the plant length 45, 60, 75 and 90 days after planting in Musanze District are ploted on Figure 2 while the results monitored 45 and 60days after planting for Gicumbi are on Figure 3. Optimum plant growth rates varying from 40cm to 60cm were recorded 75days after planting in the Andisols of Musanze. However, repeated measures analyses of variance detected no significant differences among various sources of nitrogen with regard to the plant growth rate in these soils while very significant differences ($P \leq 0.01$) were found between the same N

Table 1. Characteristics of bioslurry materials in Musanze and Gicumbi Districts (on-dry matter basis).

District	**Sector**	**Bioslurry chemical characteristics**						
		DM (%)	**OC (%)**	**TKN (%)**	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**
Gicumbi	Rukomo	47.08	21.61	0.54	0.22	0.07	0.87	0.37
	Shangasha	45.67	25.77	1.08	0.21	0.02	0.82	0.70
	Kageyo	44.76	32.55	0.63	0.14	0.04	0.81	1.21
Musanze	Busogo	47.52	22.18	0.54	0.13	0.02	0.73	0.17
	Nyange	47.17	26.48	0.97	0.12	0.06	0.91	0.85
	Kinigi	47.51	28.94	1.29	0.13	0.04	0.88	0.76
Mean values		46.62	26.26	0.84	0.16	0.04	0.84	0.68
Coefficients of variation		2.45	15.73	38.02	25.26	48.00	7.17	54.68

DM, Dry matter; OC, Organic carbon; TKN, Total Kjeldhal nitrogen; P, Phosphorus; K, Potassium; Ca, Calcium; Mg, Magnesium.

Table 2. Status of soil chemical properties of the sites prior to the experiment.

Chemical property	**Musanze**				**Gicumbi**			
	Sectors			**District**	**Sectors**			**District**
	Busogo	**Nyange**	**Kinigi**	**All**	**Rukomo**	**Kageyo**	**Shangasha**	**All**
Soil pH_{water}	6.2	6.3	6.2	6.2	5.3	5.3	5.4	5.3
Organic carbon (%)	2.2	3.2	3.6	3.0	1.9	1.6	2.4	1.9
Total nitrogen (%)	0.2	0.3	0.2	0.2	0.2	0.1	0.2	0.2
C :N ratio	14.0	13.0	16.0	14.3	12.0	13.0	12.0	12.3
Available P (ppm)	59.0	54.7	51.0	54.9	40.0	44.3	43.3	42.5
Exchangeable K^{+}	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Exchangeable Ca^{2+} (meq /100g soil)	13.5	13.8	11.8	13.0	8.0	7.7	5.0	6.9
Exchangeable Mg^{2+} (meq /100g soil)	0.5	1.4	1.4	1.1	1.5	2.4	1.8	1.9
Exchangeable Al^{3+} (meq/100g soil)	0.0	0.0	0.0	0.0	0.8	0.7	0.8	0.7
Total acidity (meq /100g soil)	1.5	1.0	1.1	1.2	2.4	2.4	1.7	2.2
Estimated CEC (meq /100g soil)	15.7	16.2	14.4	15.4	12.1	12.7	8.8	11.2

Table 3. Soil chemical properties as affected by nitrogen sources in the two soils.

Soil characteristics		**Nitrogen sources**					
		CTL000	**MIN100**	**FYM100**	**BIO040**	**BIO060**	**BIO100**
Andisols	Soil pH_{water}	6.00^{a}	6.1^{ab}	6.3^{bc}	6.4^{c}	6.3^{c}	6.3^{bc}
	Organic matter (%)	5.5^{a}	5.8^{ab}	6.1^{ab}	5.8^{ab}	6.4^{b}	6.3^{b}
	Total N (%)	0.25^{c}	0.27^{bc}	0.30^{a}	0.27^{abc}	0.29^{ab}	0.30^{a}
	Available P (ppm)	56.4^{c}	59.6^{bc}	65.2^{ab}	69.3^{a}	66.3^{ab}	69.3^{a}
	Exchangeable Mg^{2+} (meq /100g soil)	1.30^{a}	1.51^{a}	1.62^{a}	1.30^{a}	1.33^{a}	1.67^{a}
	Soil CEC (meq /100g)	17.8^{b}	18.9^{ab}	20.0^{a}	20.4^{a}	19.2^{ab}	20.5^{a}
Oxisols	Soil pH_{water}	5.2^{a}	5.2^{a}	5.5^{ab}	5.6^{b}	5.4^{ab}	5.7^{b}
	Organic matter (%)	3.3^{d}	3.7^{c}	3.8^{bc}	4.1a	3.8^{bc}	4.1^{ab}
	Total N (%)	0.16^{c}	0.19^{b}	$0.20a^{b}$	$0.19a^{b}$	0.22^{a}	0.21^{a}
	Available P (ppm)	41.1^{a}	45.8^{ab}	49.7^{b}	49.4^{b}	50.0^{b}	50.6^{b}
	Exchangeable Mg^{2+} (meq /100g soil)	1.89^{b}	2.17^{ab}	1.82b	2.08^{ab}	1.97^{ab}	2.73^{a}
	Soil CEC (meq /100g)	13.9b	14.7ab	14.9ab	15.7a	15.5ab	15.1ab

Different letters in the same row indicate significantly different values.

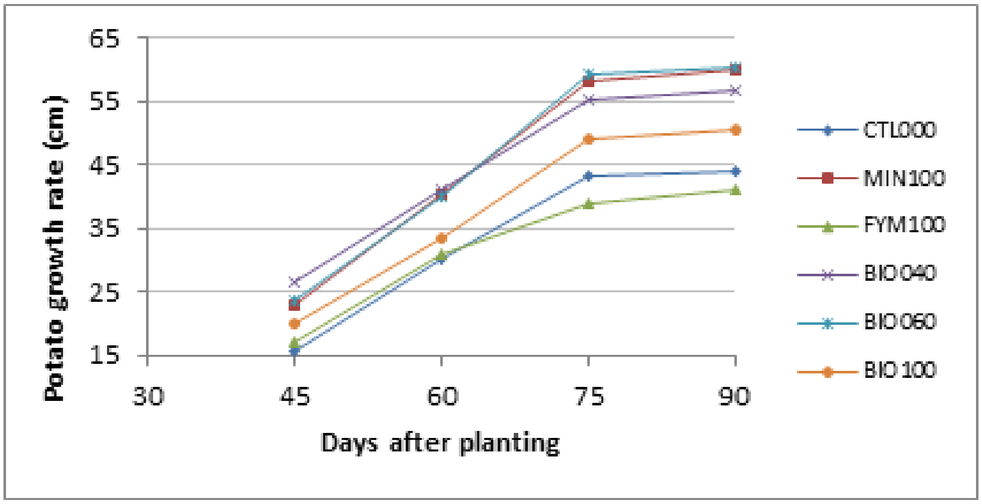

Figure 2. Effects of nitrogen sources on potato growth in Musanze Andisols.

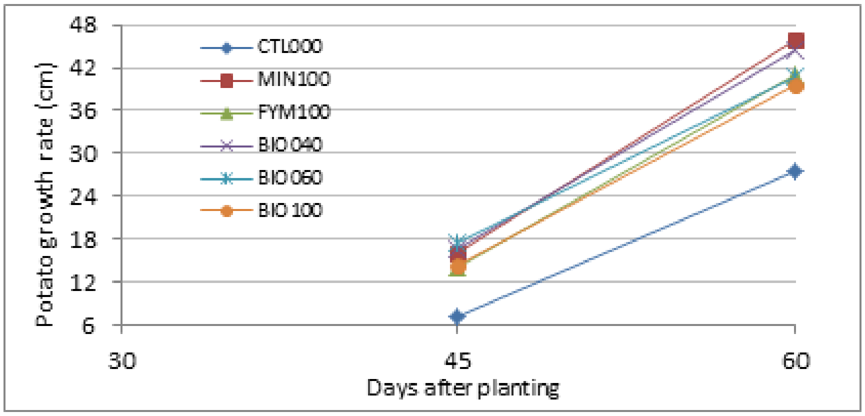

Figure 3. Effects of nitrogen sources on potato growth in Gicumbi Oxisols.

sources in the Oxisols of Gicumbi.

As anticipated, very significant differences ($P \leq 0.001$) exist between the dates of monitoring the plant growth for the two types of soils. The results on the plant growth are consistent with the growth range between 15cm and 100cm previously reported (Haque et al., 2015; Hill, 2002) and with the 60cm average growth length of Irish potato stems reported in Rwanda (MINAGRI, 1988). The plant growth was uniform across all treatments in the Andisols (Figure 1) and significant differences detected in the Oxisols were related to the lower performance of CTL000 than N sources (Figure 2). This can reasonably be related to the low organic matter of these Oxisols which implies a lower mineralization (meaning a lower N supply) and a lower water holding capacity than the Andisols. The results also validate previous studies whereby bioslurry alone (BIO100) or in combination with mineral N (BIO040 and BIO060) was as a good fertilizer as or better than chemical fertilizers on the potato growth rate (Haque et al., 2015; Haque, 2013).

Effects of treatments on the number of shoots and tubers by plant

The average number of shoots per plant as evaluated 45 days after planting ranged between 2.9 and 3.3 in the Andisols and from 2.4 to 2.9 shoots in the Oxisols (Table 4). The analyses of variance of data showed no significant differences between nitrogen sources in none of the two soils with regard to the number of shoots by plant. With regard to the number of tubers by plant, significantly

Table 4. Effects of nitrogen sources on the number of shoots 45 days after planting and the number of potato tubers by plant at harvest time.

Treatments	Musanze Andisols		Gicumbi Oxisols	
	Shoots number by plant	Tubers number by plant	Shoot number by plant	Tubers number by plant
CTL000	2.9^{a}	5.5^{a}	2.4^{a}	7.4^{a}
MIN100	3.3^{a}	7.6^{b}	2.8^{a}	12.8^{a}
FYM100	3.0^{a}	6.0^{a}	2.5^{a}	10.3^{a}
BIO040	3.3^{a}	7.9^{b}	2.7^{a}	9.4^{a}
BIO060	3.2^{a}	7.5^{b}	2.9^{a}	10.0^{a}
BIO100	3.3^{a}	6.7^{ab}	2.6^{a}	9.0^{a}

Numbers sufficed with different letters in the same column indicate significantly different values.

Table 5. Effects of different nitrogen sources on the potato tuber yield and yield quality.

Treatments	Musanze Andisols (metric tons/ha)				Gicumbi Oxisols (metric tons /ha)			
	Small	R&R	Market	Total	Small	R&R	Market	Total
CTL000	1.60^{a}	0.03^{a}	5.97^{a}	7.60^{a}	3.13^{a}	1.36^{a}	4.11^{a}	8.60^{a}
MIN100	2.87^{a}	0.07^{a}	11.96^{b}	14.90^{bc}	4.17^{a}	2.78^{a}	6.65^{b}	13.60^{b}
FYM100	2.15^{a}	0.02^{a}	7.03^{a}	9.18^{ab}	3.32^{a}	1.62^{a}	5.97^{ab}	10.91^{ab}
BIO040	2.38^{a}	1.28^{a}	11.24^{bc}	14.92^{bc}	4.35^{a}	3.48^{a}	6.87^{b}	14.70^{b}
BIO060	3.33^{a}	0.10^{a}	13.98^{c}	17.41^{c}	3.56^{a}	2.76^{a}	7.19^{b}	13.51^{b}
BIO100	2.63^{a}	0.07^{a}	9.21^{b}	11.91^{b}	3.18^{a}	3.02^{a}	7.81^{b}	14.01^{b}

Numbers sufficed with different letters in the same column indicate significantly different values.

different effects ($P \leq 0.05$) between the nitrogen sources existed in the Andisols while no such effects were found in the Oxisols. In the Andisols, bioslurry-based N sources (BIO040, BIO060, and BIO100) statistically provided higher tuber numbers than FYM100, but as equal number of tubers as chemical fertilizer (MIN100).

Potato tuber numbers are consistent with the standards established by Soltner (1985) whereby the number of potato tubers varied from 3 to 20 in normal conditions of cultivation. However, current numbers are consistent in Oxisols and much lower in Andisols than previous findings in Northern Rwanda (Nyiransabimana, 2011).

Over all, the results confirmed the effectiveness of bioslurry whether alone or in combination with mineral nitrogen fertilizer to supply nitrogen and other nutrients to the potato crop as measured by the number of potato tubers. This is also consistent with previous findings (Haque et al., 2015; Warnars, 2014; Nyiransabimana, 2011).

Effects of nitrogen sources on potato tuber yield and yield quality

The mean effects of N sources on potato tuber yields are presented in Table 5 for small size (lower than 5 cm circumference), rough or rot tubers (R&R), marketable, and total potato tuber yields for the two regions. The analysis of variance was performed on log-transformed total yield data in Andisols. Potato market yields were low, particularly in Oxisols because of a severe outbreak of the bacterial blight (Pseumonas solanacearum) during the crop gowth. The disease caused small size and R&R tubers to be much more important in Oxisols than in Andisols. However, such low yields were not exceptional under rainfed conditions as evidenced by previous findings for the region (Turamyenyirijuru, 2013; Nyiransabimana, 2011). Moreover, no significant differences were detected between N sources with regard to small size and R&R tuber yields in either soil. However, very significant differences were found in the Andisols (on log-transformed data at $P \leq 0.01$) and in the Oxisols ($P \leq 0.01$) with regard to market and total potato tuber yields.

Overall, the bioslurry-based N sources were proven as good N fertilizers as mineral N fertilizer in the two regions and better than farmyard manure only in Musanze for market potato yields. Moreover, whether statistically significant or not, combinations of mineral and bioslurry sources constantly resulted in higher yields than other treatments. This fact is a clear evidence of a beneficial symbiosis of combinations of mineral nitrogen and

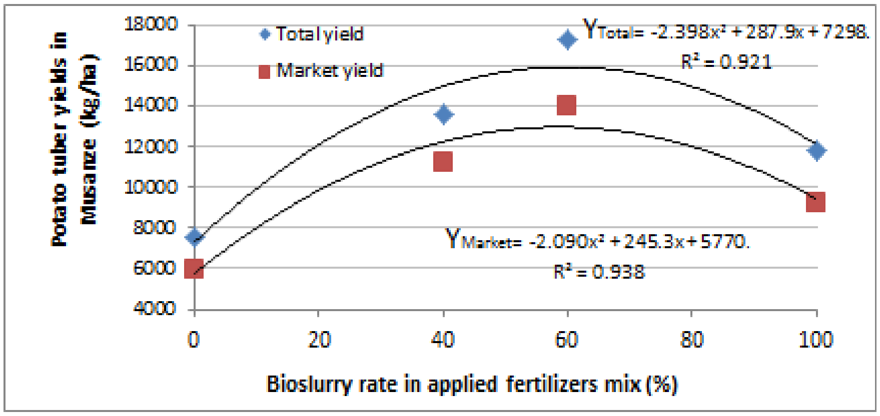

Figure 4. Effect of increasing bioslurry rate on potato yields in Andisols.

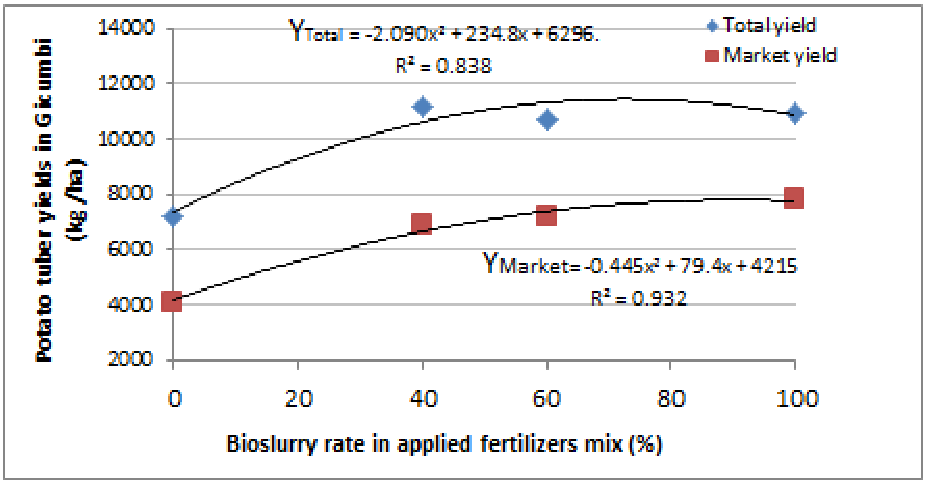

Figure 5. Effect of increasing bioslurry rate on potato yields in Oxisols.

bioslurry to feed the potato plant. Previous findings indicated that bioslurry-containing treatments resulted in as equal as or higher potato yields than mineral fertilizers alone (Haque et al., 2015). The best combinations of the two sources can be determined through the projection of the potato yield as a function of increasing bioslurry rate in the mixes of the two N sources. In this study, the zero solutions of the derivatives of the projection equations determined the best combinations of mineral N and bioslurry N for Musanze (Figure 4) and Gicumbi (Figure 5).

The computed zero-solutions of the projection equations were located at 60 and 58.7% maximum bioslurry rates in potato N fertilizer amounts for Musanze Andisols and at 56.0 and 89.2% for Gicumbi Oxisols for total and market potato tuber yields, respectively.

The high percentage of bioslurry in fertilizer mixes for market potato tuber yields in Oxisols is undoubtfully due to the importance of small size and R&R tuber yields in total tuber yields. Obviously, the interval between 40% and 60% of bioslurry in its combinations with chemical nitrogen fertilizers should contain the optimum rates producing optimum market potato tuber yields in both soils. This would represent between 40 and 60% cost reduction of chemical fertilizers from bioslurry use and a substantial extra-profit from on-farm biogas production plants. Islam (2006) in Bangladesh and Muhmood (2014) in Pakistan reported comparable results on various vegetable crops whereby the use of bioslurry reduced the application of chemical fertilizers up to 50% of N recommended amounts. However, on Kale crops (*Brassica oleracea* L.), the highest yields were harvested under 100% bioslurry when compared to increasing rates of bioslurry in its combinations with mineral fertilizers

(Haile and Ayalew, 2018).

Conclusion

The main objective of this study was to assess the efficiency of bio-slurry as a soil amendment and N nutrient source for potato crop in the Andisols and Oxisols of Northern Rwanda. Six treatments including commonly applied farmyard manure and mineral fertilizers were tested against bioslurry alone or in combination with mineral N fertilizer. The results indicated that the application of bio-slurry alone or in combinations with mineral N fertilizers contributed as much as or better than conventional farm yard manure (FYM100) to improving the soil quality (pH, organic matter content, notably). They also indicated that the application of bioslurry alone or in combinations with mineral fertilizer resulted in as good potato plant growth, tuber yield and tuber quality as or better than mineral N fertilizer alone, regardless of the soil type. The highest potato tuber market yields were harvested in MIN100 (11.96T /ha) and BIO060 (13.98T/ha) in Andisols and BIO060 (7.19T /ha) and BIO100 (7.81T /ha) in Oxisols. These yield levels are locally common under rainfed conditions. Overall, the bioslurry fractions varying from 40% to 60% in its combinations with mineral N fertilizers contain both the optimum and maximum market potato tuber yields in these two soils. This would represent an effective cost reduction varying from 40% to 60% of mineral fertilizers. However, local bioslurry appeared low-nitrogen concentrated for two possible reasons: the addition of water to get fresh manure into the biodigester and the subsequent additions of soil in the slurry pit to make it semi-solid for easy transport with domestic tools. Farmers should be better trained to avoid these additions, which reduce the quality of their bioslurry while excessively increasing its application rate.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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