OPEN ACCESS

African Journal of Agricultural Research

6 September, 2018
ISSN 1991-637X
DOI: 10.5897/AJAR
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJAR

The African Journal of Agricultural Research (AJAR) is a double blind peer reviewed journal. AJAR publishes articles in all areas of agriculture such as arid soil research and rehabilitation, agricultural genomics, stored products research, tree fruit production, pesticide science, post-harvest biology and technology, seed science research, irrigation, agricultural engineering, water resources management, agronomy, animal science, physiology and morphology, aquaculture, crop science, dairy science, forestry, freshwater science, horticulture, soil science, weed biology, agricultural economics and agribusiness.

Indexing

Science Citation Index Expanded (ISI), CAB Abstracts, CABI's Global Health Database
Chemical Abstracts (CAS Source Index), Dimensions Database, Google Scholar
Matrix of Information for The Analysis of Journals (MIAR) Microsoft Academic
ResearchGate, The Essential Electronic Agricultural Library (TEEAL)

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Agricultural Research is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

Article Copyright

When an article is published by in the African Journal of Agricultural Research the author(s) of the article retain the copyright of article. Author(s) may republish the article as part of a book or other materials. When reusing a published article, author(s) should;

Cite the original source of the publication when reusing the article. i.e. cite that the article was originally published in the African Journal of Agricultural Research. Include the article DOI
Accept that the article remains published by the African Journal of Agricultural Research (except in occasion of a retraction of the article)
The article is licensed under the Creative Commons Attribution 4.0 International License.

A copyright statement is stated in the abstract page of each article. The following statement is an example of a copyright statement on an abstract page.
Copyright ©2016 Author(s) retains the copyright of this article..

Self-Archiving Policy

The African Journal of Agricultural Research is a RoMEO green journal. This permits authors to archive any version of their article they find most suitable, including the published version on their institutional repository and any other suitable website.
Please see http://www.sherpa.ac.uk/romeo/search.php?issn=1684-5315

Digital Archiving Policy

The African Journal of Agricultural Research is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.
https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Agricultural Research encourages metadata harvesting of all its content. The journal fully supports and implements the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajar@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJAR

Submit manuscript online http://ms.academicjournals.org

Academic Journals

73023 Victoria Island, Lagos, Nigeria

ICEA Building, 17th Floor, Kenyatta Avenue, Nairobi, Kenya

Editors

Editorial Board Members

Table of Content

Vol. 13(36), pp. 1865-1873, 6 September, 2018
DOI: 10.5897/AJAR2016.11960
Article Number: D7C3EA358417
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Allometric relationships and carbon content for biomass-carbon estimation of East African Highland Bananas (*Musa spp*. AAA-EAHB) cv. *Kibuzi, Nakitembe, Enyeru* and *Nakinyika*

Daphine Kamusingize[1*], Jackson Mwanjalolo Majaliwa[2], Everline Komutunga[1], Susan Tumwebaze[3], Kephas Nowakunda[1], Priver Namanya[1] and Jerome Kubiriba[1]

[1]National Agricultural Research Laboratories, Kawanda, P.O. Box 7065, Kampala, Uganda.
[2]Department of Geography, Geo-Informatics and Climatic Sciences, Makerere University, P.O Box 7062, Kampala, Uganda.
[3]Department of Forestry, Bio-Diversity and Tourism, Makerere University, P.O Box 7062, Kampala, Uganda.

Received 16 November, 2016; Accepted 13 March, 2017

Globally, interests to increase carbon stocks have gained momentum in both woody and non-woody ecosystems. Despite efforts made to generate appropriate methods to estimate these stocks, most equations developed do not cater for intraspecific variabilities across e.g. species, regions or growth stages; especially in the case of bananas. Therefore, there is need to develop more robust equations to improve on the precision of biomass-carbon prediction especially at local scales to facilitate estimation of specific carbon stocks often lost in global assessments. This study aimed at developing cultivar-specific biomass estimation relationships and determining carbon content of EAHB cultivars at two growth stages. Plant data were collected purposively using destructive sampling techniques on farmers' plots for 4 cultivars (*Kibuzi, Nakitembe, Enyeru* and *Nakinyika*) in two agro-ecological zones: the L. Victoria crescent and the South-western farmlands in the districts of Lwengo and Mbarara respectively. Results show that biomass differed across cultivars ($P<0.001$); hence four equations (*Enyeru*, *Nakinyika, Kibuzi_Nakitembe* and Generic) were developed following an exponential function, $y=A\exp(ax)$, using diameter at breast height (DBH) as the predictor variable with an R^2 range of 82-94%. EAHB mean carbon content varied significantly with growth stage ($P<0.05$) (47.6% for maiden plants before flowering and 48.8% for mature plants with a developed bunch). This study concludes that it is important to develop cultivar-specific equations for biomass-carbon estimation of EAHB cultivars to help assess their contribution to the carbon cycle especially in future studies.

Key words: East African Highland Bananas (EAHB) cultivars, allometric equations, total plant biomass, carbon content, growth stage.

INTRODUCTION

Globally, interests to enhance carbon stocks in the biosphere have gained momentum in both woody and non-woody ecosystems as a means to address global climate change (Nair et al., 2009; Anthony et al*.,* 2011; Lal, 2011). However, considering the continuous shortage of land available for production of woody ecosystems (Henry et al., 2009), the need to find accommodative alternatives to deal with increasing atmospheric GHGs without compromising food production and economic development has to be addressed, e.g. through use of perennial crops like banana. The approach has since then received attention despite that pre-requisites to actual implementation of such initiatives require accurate verifiable methods developed to estimate biomass, carbon content and carbon stocks especially in agricultural landscapes (Singha et al*.,* 2011; Shem et al*.,* 2013) which remains a big challenge.

Nevertheless, efforts to estimate species biomass in both natural and agricultural ecosystems have been realized especially for crops like coffee, banana, commercial tree species, cocoa, etc., whose allometric equations have been globally developed (Hairiah et al., 2001; IPCC, 2003; Nyombi et al*.,* 2009; ICRAF, 2011). This has mainly been attributed, for example, to the need to explore the role of such species in the global carbon cycle through carbon sequestration monitoring, as well as for their sustainable management (Eamus et al*.,* 2000). In spite the importance of appropriate methods to estimate carbon stocks, these equations do not cater for intraspecific variabilities across e.g. species, regions or growth stage. Hence the need to develop more robust and viable equations to accurately capture the impact of region-specific and species-specific carbon contents and stocks of ecosystem components which are in most cases lost in global assessments (Hutchinson et al*.,* 2007).

Uganda is one of the largest national producers of bananas (*Musa* spp.) in the world; and is recognized as a secondary center of diversity with high levels of different cultivars observed on individual farms (Suzanne and Emile, 1999; Edmeades et al*.,* 2005; FAO, 2009). Over 75% of the cultivars are East African Highland Bananas (EAHB) (Karamura, 1998; Nantale et al., 2008). The perennial crop is an important food security crop cultivated in a wide range of agro-ecological zones and readily available throughout the year (NARO, 2001; Eledu et al*.,* 2004; Wairegi, 2010). Though the potential of bananas to sequester carbon has been reported (e.g. Lascoa et al., 2000; Christina, 2004; Oliver, 2009), there is limited knowledge on how much different cultivars contribute despite their high morphological and physiological differences. This could perhaps be attributed to the lack of cultivar-specific methods to estimate their biomass. This is because existing equations widely used in carbon studies were developed by Arifin (2001) using bananas grown in Indonesia that perhaps exhibit different morphological traits as compared to EAHB.

Nevertheless, efforts made by Nyombi et al. (2009) to develop such equations for EAHB are worth appreciating though they did not explore the use of Diameter at Breast Height (DBH) to predict plant biomass, a commonly used predictor variable in many carbon related studies (e.g. Amy et al., 2010; Arias et al., 2011 and Adeline et al., 2013 among others). In addition, DBH has been considered as the best explanatory variable for biomass prediction of several species, but also given its ease to measure and high accuracy (Shem et al., 2013). Key variables commonly used for bananas have mainly been the pseudo-stem girth-at-base, its diameter at 100cm, and or plant height (Nyombi et al*.,* 2009; Wairegi et al., 2009); hence the need to explore the use of DBH as a predictor variable for biomass of EAHB cultivars was worth considering in this study.

On the-other-hand, carbon content values are an important element to consider in any carbon related study. Though scarce, information on local carbon content values is more important than generalized ones as recommended by Timothy et al*.* (2005). This is because such data on various species e.g. bananas are essential for accurate assessment of their carbon stocks (Arias et al., 2011). However, the conversion coefficient of biomass to carbon stock of 50% that has been universally accepted and promulgated by scientific bodies, e.g. IPCC (Timothy et al., 2005; West, 2009), is subject to debate given that it perhaps does not cater for intraspecific variabilities across species, different growth stages, or even regions.

But also, other studies have proposed the use of a default carbon content conversion value of 0.46 for trees (Hairiah et al., 2010), lower than one recommended by IPCC. However, a study by Thomas and Malczewski (2007) found out that coniferous trees had a higher carbon content value of 50.9% than other hardwoods in China, while others like (Gifford, 2000) actually noted a 54.1% content for *Pinus radiate* in Australia, all higher than the 50% value. This therefore shows great uncertainties in the use of one carbon content value as opposed to another; hence a great need to estimate species-specific carbon content values to better estimate their carbon stocks. This could also be considered for different growth stages for species like banana with different development stages that exhibit several carbon content potential components. Therefore, this study also determined the actual carbon content value of EAHB to

*Corresponding author. E-mail: kdaphine@yahoo.com

minimize over or under estimation of carbon stocks that could perhaps be brought about by the use of general values.

MATERIALS AND METHODS

Study area

Plant biomass-carbon data were obtained in 2013 from two distinct agro-ecological zones; that is, the Lake Victoria Crescent and South-western Grass Farmlands in Kisekka and Nyakayojo sub-counties of Lwengo and Mbarara districts respectively. These were classified as potential banana production areas by Eledu et al. (2004). Mbarara district lies at a high altitude of about 1400 m above sea level (0°20.5'S 30°31'E) and Lwengo at a low altitude range of 1080-1330 m above sea level (00°24'S 31°25'E) (Nantale et al*.,* 2008; Kemigabo and Adamek, 2010). Both areas experience a bimodal mean annual rainfall range of about 1000-1500 mm (Lwengo) and 1000-1200 mm (Mbarara). Their mean annual temperature range lies between 20-25°C. According to the 1998 FAO soil classification, the soil types are acric ferrasols, and dystric regosols and lixic ferrasols for Kisekka and Nyakayojo respectively. However, to minimize variability across zones, all farms selected were comprised of the ferralsol soils given that they are deep in nature and cover about 60% of the potential banana production area for Uganda (Eledu et al*.,* 2004).

Farm site selection

Based on the preliminary findings of the reconnaissance survey conducted in December 2012 and with the aim of minimizing the effect of potential confounding factors, participating farmers were purposively selected following a set of criteria: i) The farm had all the cultivars of interest; ii) The plantation was mature (20 to over 50 years); iii) All farms in a given region existed in a similar soil type classification and relatively same altitude range; iv) The farmer was willing to participate fully in the study. (ii) and (iv) were also considered for the same reason in other studies (e.g. Nantale et al*.,* 2008; Wairegi et al., 2009). In total therefore, 14 farmer plantations (7 in each area) were considered since they were the only ones meeting the criteria; but also considering the availability of resources. Four cultivars (*Kibuzi* and *Nakitembe* existing in both sites, and *Enyeru* and *Nakinyika* being unique to Mbarara and Lwengo respectively) were selected because they had a higher population density than others identified, similar to observations by Wairegi et al. (2009); and their total biomass allometric relationships had not been developed before.

Biomass estimation

In each sampling plot, all individuals belonging to the cultivars of interest were inventoried *in-situ* before destructive sampling (ICRAF, 2011). Estimation of total plant biomass therefore included non-destructive sampling measurements (Height and Diameter) of individual banana stems important for use in the allometric models generated for this study as suggested by Wairegi et al. (2009) and ICRAF (2011). To minimize bias and cater for variability, six individual mats, two for each cultivar, were purposively identified anywhere on the same farm. These were then tagged for excavation for dry weight biomass and oven-dry carbon content determination. Care was taken to ensure that mats selected had at least two individuals at different growth stages; that is, H1 (maiden plant before flowering, at least half or more the height of H2) and H2 (plant at true phonological maturity with a developed bunch). Therefore, a total 84 mats (14 per cultivar per site) were sampled. For every mat, total plant biomass (TPB) of selected plants was obtained and used to develop cultivar specific allometric relationships. In general, allometric relationships for trees are best taken at DBH (1.3m) in reference to Brown et al*.* (1989). However, a number of studies such as Wairegi et al. (2009) and Nyombi et al. (2009) have developed similar relationships for EAHB bananas considering Girth at base (G^{Base}) and Diameter at 1 m (D^{100cm}); and height. Therefore, in this study, all the three diameter levels and height were considered to find out which one best predicts the relationship for a specific cultivar. Girth at base was calculated as πD.

Individual plants were then carefully dug out from the soil and prepared following procedures detailed in Nyombi et al. (2009). Sub-samples of each part (pseudo-stem, leaves, corm, peduncle and fingers), 250 g each, were weighed, bulked and carried to the Soil Science Laboratory in Kawanda. These were oven dried to constant weight at approximately 70°C for 48 h (Timothy et al., 2005). In total, 1001 sub-samples representing all plant parts for all cultivars were obtained (that is, 420 for H1 class and 581 for H2; each class comprising of 5 and 7 samples per individual respectively). Total plant part dry mass (biomass) was then calculated based on an equation obtained from Timothy et al. (2005); where:

$$DryMass(kgs) = \left[\frac{\text{SubsampleDry Mass}}{\text{SubsampleFresh Mass}}\right] \times FreshMass\,of\,Whole\,Sample$$

Biomass data was then regressed with all the diameter levels and or plant height as explanatory variables to develop power equations; and one with the best explanatory power was selected and linearized (Nyombi et al., 2009) as below:

$$In(y) = c + aIn(x)$$

Where: *y* is the total dry plant biomass (Kg) (corm, pseudo-stem, leaves (H1) or corm, pseudo-stem, leaves, peduncle and fingers (H2)); *c* a constant; *a* the equation parameter; and *x* the explanatory variable (diameter, girth or height). The choice to estimate total plant biomass as opposed to several other carbon studies was due to the morphological nature of bananas where the corm remains the true stem of the plant not the pseudo-stem (UNCST, 2007). All data collected by destructive sampling was used for model calibration and validation.

EAHB carbon content determination

Out of all the plant individuals obtained through destructive sampling, six cultivar specific individuals with their sub-samples (corm, upper stem, middle stem, lower stem, leaf, and or fruit and peduncle), originally dried for biomass determination were randomly sampled following a sampling design of (3 cultivars×2 sites×7 (or 5) parts×6 replicates). A total of 432 sub-samples (H2:252 and H1:180) were selected for plant part carbon content determination following procedures laid out in Okalebo et al. (2002) for plant carbon content analysis.

Data analysis

All data were statistically analyzed using GenStat software

Table 1. Regression analysis of biomass across variables variate: In_total_biomass.

Variable	*Enyeru*				*Nakinyika*				*Kibuzi_Nakitembe*				*Pooled*			
	v.r.	***F pr***	***SE.***	***R^2***	***v.r.***	***F pr***	***SE.***	***R^2***	***v.r.***	***F pr***	***SE.***	***R^2***	***v.r.***	***F pr***	***SE.***	***R^2***
In_G_Base	3.34	0.079	0.501	0.080	3.29	0.081	0.563	0.078	20.50	<.001	0.535	0.151	48.76	<.001	0.533	0.223
In_D_100	81.16	<.001	0.263	0.755	149.82	<.001	0.219	0.851	540.97	<.001	0.237	0.833	760.01	<.001	0.247	0.823
In_DBH	168.20	**<.001**	0.093	**0.933**	214.51	**<.001**	0.187	**0.891**	762.88	**<.001**	0.205	**0.876**	1123.36	**<.001**	0.210	**0.873**
In_H	57.20	<.001	0.299	0.684	192.01	<.001	0.197	0.88	351.15	<.001	0.282	0.764	446.99	<.001	0.303	0.732

G_Base was the girth at base; D_100 the diameter at 100 cm; DBH the diameter at 130 cm and H the height. N for *Enyeru*, *Nakinyika*, *Kibuzi_Nakitembe* and Pooled data were 28, 28, 112 and 168 respectively.

(v.13.3.5165). Descriptive statistics used to explain the distribution of biomass across cultivars were obtained for region specific and pooled data. ANOVA was run to test for any significant differences, if any, in biomass across the factors (cultivar type and growth stage) considering the l.s.d of their means at a 95% confidence level. Prior to equation development, simple linear regressions were run across cultivars for all variables (DBH, Height, Girth at base and Daimeter_100 cm) with biomass as the response to obtain a predictor variable (s) with a better explanatory power to predict biomass. Following results of Anderson-Darling normality test, data used in the generation of the equations were *log* transformed to fit a linear equation because the raw data were not symmetrically distributed; but also to increase on the sensitivity of the statistical tests (Seth, 2008). To develop the allometric relationships, half the data were used for equation calibration and the other half for validation.

One-way ANOVA was also performed to test for any significant differences in carbon content of cultivars as well as growth stages at a 95% confidence level. Mean values of the carbon content for the various plant parts were also determined. However, given that the degree of freedom for growth stage was 1 (very small to base a decision on), the difference in carbon content across growth stages was also tested using a two sample T-test assuming equal variance at a 95% confidence level (details of the analysis not presented in this document).

RESULTS

The average total dry biomass amounts across all cultivars sampled in Mbarara were generally higher (*Kibuzi*, 8.13±4.68; *Nakitembe*, 7.98±3.91 and *Enyeru* 9.15±4.58) than those in Lwengo (*Kibuzi*, 5.69±2.60, *Nakitembe* 5.59±2.98 and *Nakinyika* 4.89±2.45). Therefore, the relatively high average biomass amounts for pooled data (6.89±3.95) could perhaps be explained by the biomass amounts resulting from data obtained from Mbarara. The standard errors across all cultivars were high. The variation could be attributed to the differences in biomass that was obtained from plant individuals growing at different stages (H1 and H2). ANOVA results showed a significant difference in biomass for both factors (cultivar type and growth stage) with $P<0.001$. However, basing on the l.s.ds of the means, biomass was different for cultivars *Enyeru* and *Nakinyika*, and similar for *Kibuzi* and *Nakitembe*.

Therefore, it was on this basis that three allometric relationships were developed for biomass prediction of the cultivars (that is, *Enyeru, Nakinyika and Kibuzi_Nakitembe*). Also, a generic equation for EAHB was developed to ascertain how best it could predict biomass for other cultivars. Regression results for all cultivars as well as pooled data showed that DBH was highly correlated with a coefficient of determination (R^2) of above 87% compared to others (Table 1). These results were based on all the data for a specific cultivar or set of cultivars. It was therefore on this basis that DBH was selected as a better explanatory variable for biomass prediction of EAHB cultivars.

All equations were highly correlated with DBH ($P<0.001$) with R^2 between 82-94% being higher in cultivar specific equations of *Enyeru* and *Nakinyika* compared to a set of cultivars (that is, *Kibuzi_Nakitembe* and the Generic equation) (Figures 1 and 2, and Table 2).

A generic equation was also developed for use in similar studies in future for EAHB given that its predictions were highly correlated across all cultivars giving an R^2 of 82, 90 and 88% for *Enyeru*, *Nakinyika* and *Kibuzi_Nakitembe*; respectively (details of analysis not presented in this document). These were not significantly different from those predicted by the specific or a combination of cultivars as shown in Figures 1 and 2 above. Therefore, the linear equations that were developed for predicting total plant biomass of specific cultivars were as follows:

Carbon content of EAHB

On average, carbon content of EAHB across parts followed the pattern: fruit>leaf>corm>stem> peduncle for H2; and leaf>corm>stem for H1

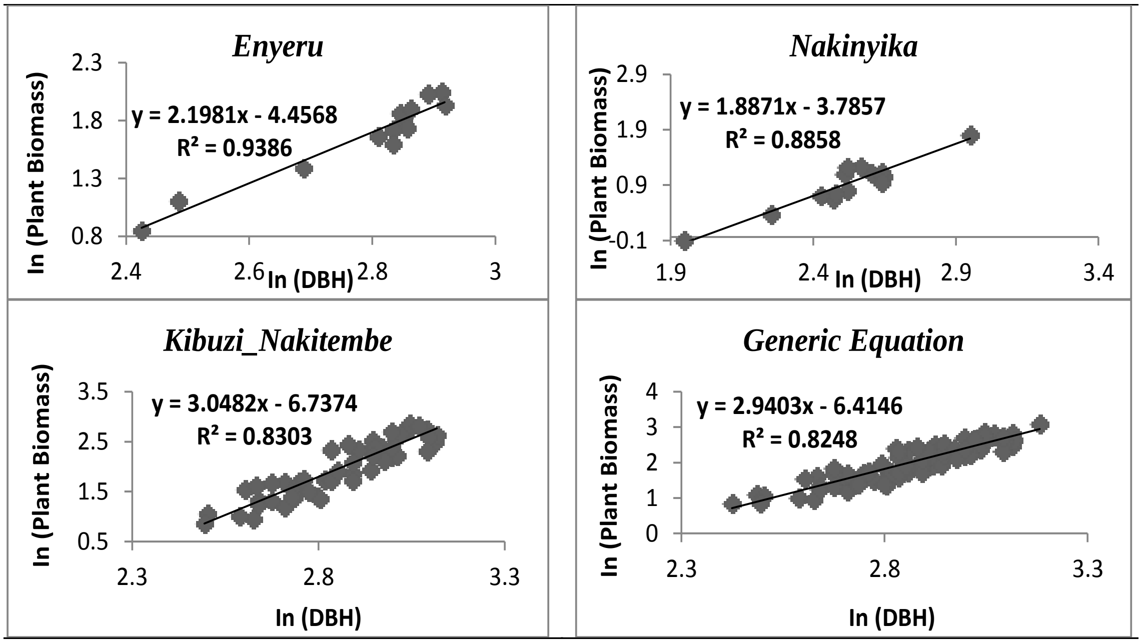

Figure 1. Calibrated allometric relationships for EAHB cultivars.

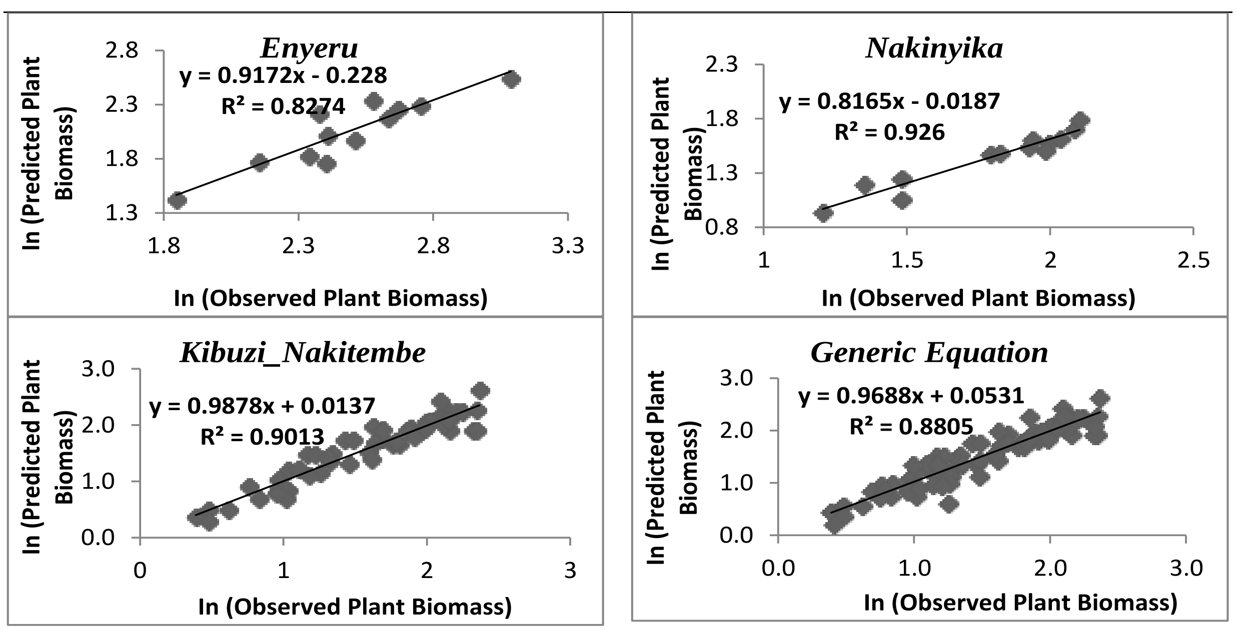

Figure 2. Validated allometric relationships for EAHB cultivars.

(Figure 3). However, in the interest of this study, focus was put on the carbon content of cultivars and or growth stages. Results from One Way ANOVA showed no significant difference in carbon content across cultivars (*P*>0.05) but growth stages (*P*<0.05). The later was also confirmed by the results obtained from the T-test (*P*<0.05). Therefore, 47.6 and 48.8% were the means of the carbon content considered in this study for H1 and H2; respectively as obtained from the T-test. Nevertheless, in studies where these growth stages are

Table 2. Summary of equations developed for total biomass estimation of EAHB cultivars.

Cultivar	n	Model	c	a	S.E (a)	S.E (c)	R^2	R^2 (adj.)	*P*
Enyeru	14	$In(y)=c+aIn(x)$	-4.457	2.198	0.170	0.473	0.939	0.933	0.000
Nakinyika	14	$In(y)=c+aIn(x)$	-3.786	1.887	0.196	0.493	0.886	0.876	0.000
Kibuzi_Nakitembe	56	$In(y)=c+aIn(x)$	-6.730	3.048	0.189	0.540	0.830	0.827	0.000
Generic	84	$In(y)=c+aIn(x)$	-6.415	2.940	0.151	0.432	0.825	0.823	0.000

a and *c* are regression coefficient constants, *y*, dry plant biomass (Kg), and *x,* the explanatory variable DBH.

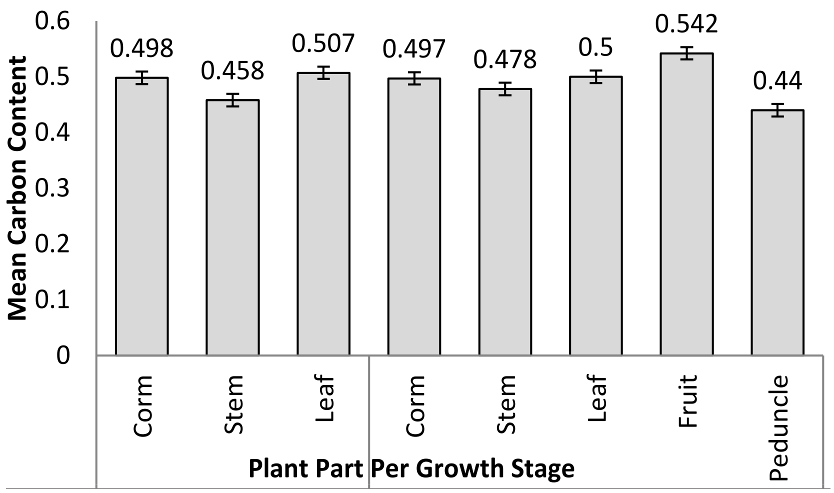

Figure 3. Carbon content means of plant parts.

not considered e.g. at flowering, then the mean value of 48.2% can be used as the carbon content of EAHB.

DISCUSSION

Allometric relationships for biomass estimation of EAHB cultivars

The allometric equations developed in this study were cultivar specific (Figures 1 and 2; and Table 2) though results showed that total dry biomass was significantly different across both cultivars and growth stages. These findings are in line with Nyombi et al. (2009) suggestion on the need to develop growth stage (or cultivar) specific allometrics given that dry biomass of EAHB differs across ontogeny. This was also evident considering the differences in the means of dry biomass across cultivars in the different regions except for cultivars *Kibuzi* and *Nakitembe* whose biomass was not significantly different. Similarities exhibited in biomass obtained from *Kibuzi* and *Nakitembe* cultivars could perhaps be attributed to the fact that *Kibuzi* shows some similar traits as those of the *Nakitembe* clone set where *Nakitembe* cultivar belongs (Karamura, 1998). However, in the interest of this study, growth stage specific allometrics were not developed since focus was put on developing cultivar specific equations using data obtained from both stages; hence their applicability to all stages of growth considered in this study.

Linear regressions run on all potential total plant biomass predictor variables (height, girth at base, DBH and diameter at 100 cm) revealed that DBH was the best predictor variable with an R^2 ranging between 87-93% across cultivars (Table 1) similar to observations made for *Eucalyptus* in Kenya (Shem et al., 2013). Results are also in line with the predictor variable used for above ground biomass estimation of bananas developed in Indonesia by Arifin (2001) a widely used allometric relation for bananas in carbon studies (e.g. in Oliver, 2009; Henry et al., 2009; Hariah et al., 2010 among others) though DBH was taken as 135 cm. The variable is also commonly preferred for other perennial crops like trees, coffee, cocoa, etc (Arifin, 2001; Basuki et al., 2009; Amy et al., 2010; Twongyirwe, 2010; Michiel et al., 2011; Sirike, 2012; Mugasha et al., 2013); hence making it a key variable to consider in such a study.

Girth at base however, emerged the weakest of all variables across cultivars (except *Kibuzi_Nakitembe* whose R^2 was very small) not being significantly related to biomass; results deviating from those obtained by Nyombi et al. (2009). This could perhaps be attributed to the fact that DBH has not been explored before for biomass estimation of EAHB among other factors. Important to note however is that the equations developed in this study (Table 2) cater for intraspecific variabilities that could perhaps be brought about by the type of cultivars used, age, and site conditions (edaphic and climatic variability) as noted by Juan et al. (2010). But also such variabilities could be as a result of increased variance in total dry biomass of individuals due to growth stages that resulted in high standard errors across all cultivars as well as pooled data (Table 2) (Nyombi et al., 2009) including on-farm variations and management among others.

Despite that the 3 parameters (DBH, height and diameter at 100 cm) gave high R^2 values, all could not be included in the model as this would be considered inappropriate; but also to eliminate cases of redundant parameters with high co-linearity in one equation function (Montgomery and Peck, 1992). However, in cases where DBH data is not available (e.g. when a plant is still young), height can be used as an alternative parameter for plant biomass estimation (Nyombi et al., 2009; Mugasha et al., 2013) though it is relatively difficult to measure as well as time consuming compared to DBH.

The fact that biomass quantities were significantly different for region specific cultivars but similar for common ones was proof enough to generate specific equations instead of a generalized one given that the former has the potential to improve the accuracy of prediction (Wairegi, 2010). However, developing such equations for more than 80 EAHB cultivars could be challenging due to limited resources (Karamura, 1998; Gold et al., 2002; Wareigi, 2010). Therefore, in cases where a cultivar specific equation is absent, the generic equation developed in this study could perhaps be applied on cultivars of more or less similar origin after all its prediction gave significantly high R^2 values for all cultivars ranging from 82-90%; not very different from specific ones.

Carbon content of EAHB

In general, the average carbon content of EAHB was found to be 48.2% relatively lower than the recommended value of 50% (Timothy et al., 2005; IPCC, 2006). Results are in line with those obtained for broadleaf tree species whose average C. content was minor than 50% for the whole plant (Arias et al., 2011) and among plant parts as reported in coniferous species in a study by Yen et al. (2009). Also, the value is very close to the 48% C content value that was used in a study by Shackleton and Scholes (2011) but slightly higher than the 46 and 47.9% values used for the conversion of dry wood biomass to carbon (Hairiah et al., 2010; ICRAF, 2011). All in all, results obtained in this study fall in the range of 46-49% carbon content values recommended for use in the tropics for tree species with DBH >10 cm (IPCC, 2006) considering that all individuals used for carbon content determination in this study had a DBH value >10 cm (Figure 3).

The difference of 1.2% in C content between growth stages could be as a result of one stage (H1) lacking both the fruit and peduncle components present in the other (H2) given that the components common to both show no significant difference across stages (Figure 3). Therefore, to obtain relatively accurate estimates for carbon stocks of cultivars in this study, it was considered prudent enough to use the growth stage specific C. content values, that is, 47.6% (H1) and 48.8% (H2) since they were locally available as recommended by Timothy et al. (2005).

In comparison with say tree components, generally bananas have more C. content in leaves at any stage (50-50.7%) compared to tree species like *V. guatamalensis* (41.0%) but not far from *P. caribeae* (49.6%) as observed in a study by Arias et al. (2011). This could be attributed to the fact that banana as a whole possesses large leaves as compared to any broad leaved tree species. However, comparing stems, EAHB contain less carbon content (45.8-47.8%) than one observed for tree species (e.g. *P. caribeae* with a 50.8% content). This could be explained perhaps by the pseudo-stem nature of banana stems containing high moisture content (Jing et al., 2010) as opposed to wood deposit present in trees. Therefore, considering these results, the 50% carbon content coefficient would be a relatively high estimate for species like EAHB (48.2%) but could be a fair rule of thumb in cases where the specific carbon content is missing (Arias et al., 2011).

Conclusions

Banana biomass can be accurately estimated using an exponential function (y=Aexp(ax)). The values of the constants tend to vary from one cultivar to another. The use of DBH as the best predictor variable for biomass of EAHB cultivars was confirmed as recommended for use in most carbon related studies. Carbon content was significantly different across growth stages ($P<0.05$) and not cultivars ($P>0.05$). The mean carbon content of EAHB is 48.2% slightly higher than the carbon content value (47.6%) of banana plants before flowering and lower than those at maturity with a content value of 48.8%. All the values were found to be lower than the globally recommended 50% value by IPCC.

RECOMMENDATIONS

Generally, the allometric equations developed for biomass estimation of EAHB cultivars (*Enyeru, Nakinyika, Kibuzi and Nakitembe*) cater for intraspecific variabilities, growth stage, cultivar type and site conditions considering DBH as a key predictor variable as observed in other carbon related studies. Also, the determination of the actual carbon content of these bananas was timely as this was used to relatively estimate the actual plant carbon stock of the cultivars that would perhaps be lost in the use of readily available values. Therefore, more biomass prediction equations should be developed for other banana categories like plantains to ascertain the contribution of the entire banana cropping system to the global carbon cycle given that EAHB cultivars are not grown in isolation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to the Rockefeller Foundation through the National Banana Research Program /NARO (RF Grant # CPR206) for supporting this study.

REFERENCES

Adeline F, Jean-Louis D, Jean-François G, Nils B, Philippe L (2013). Tree allometry in Central Africa: Testing the validity of pantropical multi-species allometric equations for estimating biomass and carbon stocks. Forest Ecology and Management 305:29-37

Amy SIW, Asase A, Hadley P, Mason J, Kwesi OF, Preece D, Spring N, Norris K (2010). Management strategies for maximizing carbon storage and tree species diversity in cocoa-growing landscapes. Agriculture, Ecosystems and Environment. 138:324-334.

Anthony WDA, John BB, Shawn F, Brian JP (2011). Forest management for mitigation and adaptation to climate change: Insights from long-term silviculture experiments. Forest Ecology and Management 262(5):803-816.

Arias D, Calvo-Alvarado J, Richter deB D, Dohrenbusch A (2011). Productivity, aboveground biomass, nutrient uptake and carbon content in fast-growing tree plantations of native and introduced species in the Southern Region of Costa Rica. Biomass and Bioenergy 35:1779-1788.

Arifin J (2001). Estimasi Cadangan Karbon pada Berbagai Sistem Penggunaan lahan di Kecamatan Ngantang, Malang. Thesis S1. Jurusan Tanah, Fakultas Pertanian. Universitas Brawijaya. Malang.

Basuki TM, Van Laake PE, Skidmore AK, Hussin YA (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. Forest Ecology and Management 257:1684-1694.

Brown S, Gillespie AJR, Lugo AE (1989). Biomass estimation methods for tropical forest with application to forest inventory data. Forest Science 35:881-902.

Christina LP (2004). Carbon Storage in Coffee Agro-ecosystems of Southern Costa Rica: Potential Applications for the Clean Development Mechanism, M.Sc. Thesis York University, Canada

Eamus D, McGuinness K, Burrows W (2000). Review of allometric woody biomass for Queensland, the Northern Territory and Western Australia. Canberra, Australia. Australian Greenhouse Office, August. Report no. 5A:64.

Edmeades S, Smale M, Karamura D, Smale M (2005). Demand for cultivar attributes and the biodiversity of bananas on farms in Uganda. Valuing crop biodiversity: on-farm genetic Resources and Economic Change 27:97-118.

Eledu CA, Karamura EB, Tushemereirwe WK (2004). Agro ecological distribution of banana systems in the great lakes region. African Crop Science Journal 12(1):33-42.

Food and Agriculture Organization (FAO) (2009). Food and Agriculture Organization and emergencies; consolidated appeals for Uganda for 2008. http://www.fao.org/emergencies/tce-appfund/tceappeals/consolidated-appeals/uganda/en/ Accessed on 20.Nov.2012. at 9:47am.

FAO/ISRIC/ISSS (1998). World reference base for soil resources. 84 World Soil Resources Reports. Food and Agriculture Organization of the United Nations, International Soil Reference and Information Centre and International Society of Soil Science. http://www.fao.org/3/a-a0510e.pdf

Gifford R (2000). Carbon contents of above-ground tissues of forest and woodland trees. Canberra: Australian Greenhouse Office (17).

Gold CS, Kiggundu A, Abera AMK, Karamura D (2002). Diversity, Distribution and Farmer Preference of Musa Cultivars in Uganda. Experimental Agriculture 38:39-50.

Hairiah K, Dewi S, Agus F, Velarde S, Ekadinata A, Rahayu S, Van NM (2010). Measuring carbon stocks across land use systems: A Manual, Bogor, Indonesia. World Agroforestry Centre (ICRAF), SEA Regional Office 155 p.

Hairiah K, Sitompul SM, Van Noordwijk M and Palm C (2001). Methods for sampling carbon stocks above and below ground, Published by International Centre for Research in Agroforestry, Bogor, Indonesia.

Henry M, Tittonell P, Manlay RJ, Bernoux M, Albrecht A, Vanlauwe B (2009). Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. Agriculture, Ecosystems and Environment 129:238-252.

Hutchinson JJ, Campbell CA, Desjardins RL (2007). Some perspectives on carbon sequestration in agriculture. Agricultural and Forest Meteorology 142:288-302.

ICRAF (2011). Guidelines for establishing regional allometric equations for biomass estimation through destructive sampling, Version 1.0, Nairobi Kenya.

Intergovernmental Panel on Climate Change (IPCC) (2003). Good practice guidance for land use, land-use change and forestry. In: Penman J, (ed). *IPCC national greenhouse gas inventories programme*. Hayama, Japan: Institute for Global Environmental Strategies (IGES) for the Intergovernmental Panel on Climate Change (IPCC).

IPCC (2006). Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T and Tanabe K (eds). Published: IGES, Japan.

Jing YT, Chin LL, Keat TL, Kok TT, Subhash B (2010). Banana biomass as potential renewable energy resource: A Malaysian case study. Renewable and Sustain. Energy Reviews 14(2):798-805.

Juan CLU, Jorge ART, Mailing VRA, Álvaro de Jesús LT (2010). Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests. Forest Ecology and Management 260:1906-1913.

Karamura DA (1998). Numerical Taxonomic Studies of the East African Highland Bananas (Musa AAA-East Africa) in Uganda. A thesis submitted for the degree of Doctor of Philosophy, Department of Agricultural Botany, University of Reading.

Kemigabo C, Adámek Z (2010). Environmental conditions and natural food resources for commercial fish production in the valley dams of Mbarara District, Uganda. Agricultura Tropica et Subtropica 43:4.

Lal R (2011). Sequestering carbon in soils of agro-ecosystems. Food Policy 36:S33-S39.

Michiel VB, Johannes R, Dylan C, Frans B, Jefferson SH (2011). Estimating carbon stock in secondary forests: Decisions and uncertainties associated with allometric biomass models. Forest Ecology and Management 262:1648-1657.

Montgomery DR, Peck EA (1992). Introduction to linear regression analysis. Published by Wiley, New York, USA P. 504.

Mugasha WA, Tron E, Ole MB, Malimbwi RE, Shabani AOC, Eliakimu Z, Katani JZ (2013). Allometric models for prediction of above and belowground biomass of trees in the Miombo woodlands of Tanzania. Forest Ecology and Management 310:87-101.

Nair PKR, Kumar BM, Nair VD (2009). Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science 172:10-23.

Nantale G, Kakudidi EK, Karamura DA, Karamura E, Soka G (2008). Scientific basis for banana cultivar proportions on-farm in East Africa. African Crop Science Journal 16(1):41-49.

NARO (2001). Multi-locational banana germplasm evaluation trials: Third report. Dar es Salaam, Tanzania, NARO Manuscript, Unpublished.

Nyombi K, Van Asten PJA, Leffelaar PA, Corbeels M, Kaizzi CK, Giller KE (2009). Allometric growth relationships of East Africa highland bananas (*Musa* AAAEAHB) cv. *Kisansa* and *Mbwazirume*. Annals of Applied Biology 155:403-418.

Okalebo JR, Gathua KW, Woomer PL (2002). Laboratory Methods of Soil and Plant Analysis: 2nd Edition, TSBF-CIAT and SACRED Africa, Nairobi.

Oliver JZ (2009). Biomass and carbon stocks inventory of perennial vegetation in the Chieng Khoi watershed, NW Vietnam. M.Sc. Thesis University of Hohenheim, Germany.

Lasco RD, Lalesa JS, Arnuevo T, Guillermo IQ, Jesus AC, Medrano R, Bajar OF, Mendoz CV (2000). Carbon dioxide (Co_2) storage and sequestration in the Leyte geothermal reservation, Philippines In: Guillermo Q, Agnes C, deJesus, Reinero, Medrano, Orlando F, Bajar F, Cirilo, Mendoza V (Eds) Proceedings World Geothermal Congress Kyushu -Tohoku, Japan, May 28-June 10, 2000. Renew. Energy 25(2):307-315.

Seth R (2008). Transform your data. Nutrition 24:492-494.

Shackleton CM, Scholes RJ (2011). Above ground woody community attributes, biomass and carbon stocks along a rainfall gradient in the savannas of the central lowveld, South Africa. South African Journal of Botany 77:184-192.

Shem K, Johannes D, Catherine M, van Noordwijk M, Henry N (2013). Allometry and partitioning of above and below-ground biomass in farmed eucalyptus species dominant in Western Kenyan agricultural landscapes. Biomass Bioenergy 55:276-284.

Singha V, Ashish T, Satya PS, Kushwaha, Vinay KD (2011). Formulating allometric equations for estimating biomass and carbon stock in small diameter trees. Forest Ecology and Management 261:1945-1949.

Sirike J (2012). Impact of land use/cover change on carbon stock dynamics and river water quality: A case study of River Atari-Kapchorwa District. M.Sc. Thesis submitted to Makerere University, Kampala

Suzanne S, Emile F (1999). Musa production around the world-trends, varieties and regional importance In: INIBAP Annual Report 1998. Montpellier (FRA). Focus paper 2:42-47.

Thomas SC, Malczewski G (2007). Wood carbon content of tree species in Eastern China: Interspecific variability and the importance of the volatile fraction. Journal of Environmental Management 85:659-662.

Timothy P, Sarah W, Sandra B (2005). Sourcebook for Land Use, Land-use Change and Forestry Projects. Tizikara C, Baguma D, Mikenga S (Eds).

Twongyirwe R (2010). Dynamics of forest cover conversion in and around Bwindi Impenetrable forest and impacts on carbon stocks and soil properties. MSc. Thesis submitted to Makerere University, Kampala.

Uganda National Council for Science and Technology (UNCST) (2007). The Biology of Bananas and Plantains. https://www.scribd.com/document/102802333/Biology-of-Bananas-and-Plantains-bz-Jul07

Wairegi LWI, vanAsten PJA, Tenywa M, Bekunda M (2009). Quantifying bunch weights of the East African Highland bananas (*Musa* spp. AAA-EA) using nondestructive field observations. Scientia Horticulturae 121(1):63-72.

Wairegi LWI (2010). Management practices and opportunities in East African highland bananas (*Musa* spp. AAA-EA) production in Uganda. Phd Thesis, Wageningen University.

West PW (2009). Tree and forest management. Springer-Velag, Berlin. Heidelberg P 53.

Yen TM, Ai LM, Li CL, Lee JS, Huang KL (2009). Aboveground carbon contents and storage of three major Taiwanese conifer species. Taiwan Journal of Forensic Sciences 24(2):91-102.

Vol. 13(36), pp. 1874-1879, 6 September, 2018
DOI: 10.5897/AJAR2018.13355
Article Number: 625CC2C58419
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Performance of varieties of green manure in conventionally used soil

Amilcar Isidro Servín Niz*, Wilfrido Daniel Lugo Pereira, Derlys Fernando López Ávalos, Alexis Saúl Muñoz Pérez, Modesto Osmar Da Silva Oviedo and Eulalio Morel López

Universidad Nacional de Concepción (UNC), Concepción, Paraguay.

Received 27 June, 2018; Accepted 30 July, 2018

The objective of this research was to evaluate the performance of different types of summer green manures in conventionally used soil. This research project was carried out in the district of Concepción (Paraguay). A Randomised Complete Block Design (RCBD) was used, consisting of four treatments and five repetitions. The treatments were *Mucuna pruriens* (T1); *Canavalia ensiformis* (T2); *Dolichos lablab* (T3) and *Cajanus cajan* (T4); each experimental unit had an area of 10 m^2. The measurements that were evaluated were the green mass of weeds at 60 and 90 DAE, and the production of green mass and dry mass by each of the evaluated varieties of green manure crops at 90 DAE. The results were analysed using the Tukey Test at the 5% level of probability. The results that were obtained show that there were differences in the production of green mass: the biggest production was shown by T2 with 27.6 mg ha^{-1}. The biggest producer of dry mass was T4 with 7.06 mg ha^{-1}.

Key words: *Cajanus cajan, Canavalia ensiformis, Dolichos lablab, Mucuna pruriens.*

INTRODUCTION

The use of leguminous species as green manure for the improvement of soil through the incorporation of large quantities of organic material, whether in the form of green matter or crop stubble, is a common practice and recommended for the improvement and maintenance of the organic material content and productivity of soils in almost all of the world's production regions.

Green manures are cultivated plants that provide benefits to the soil, generally during the flowering period, with the aim of achieving agronomic improvement. They are grown between rows of crops in fruit plantations or between two main crops that are temporally separate in rotation. At times, the green manure is a companion plant during part of the cycle of the main crop (Guzmán and Alonso, 2008).

Soil degradation understood as human-caused processes that reduce current and/or future capacity of the soii, is related to climate, the intrinsic characteristics of the soil, and above all, to deforestation (Ramírez et al., 2011). Its main effect is the modification of the micro ecosystem within which life develops in the soil. Additionally, bad practices for working the soil should be mentioned, as they do not favour the improvement of the physical, chemical and biological properties of soil.

For this reason, green manures can be used as part of the rotation system or as companion plants to crops to

*Corresponding author. E-mail: servinamilcar@gmail.com.

facilitate the task of soil recovery by small-scale farmers. The use of green manures seeks to improve the physical, chemical and biological properties of the soil; techniques that cause deleterious effects on life forms within the soil are not employed. The present research project displays the importance of the use of summer green manures for the production of organic material.

The use of organics plays a major role in maintaining soil health due to buildup of soil organic matter; beneficial microbes. To sustain the soil fertility and crop productivity, the role of organic manures and fermented organic nutrients are very important. The organic fertilizers in addition to nutrients contain microbial load and growth promoting substances which helps in improving the plant growth, metabolic activity and resistance to pest and diseases. Boosting yield, reducing production cost and improving soil health are three inter-linked components of the sustainable triangle. Therefore, suitable combination of chemical fertilizer and organic manures cultures need to be developed for particular cropping system and soil. The organic products besides supplying nutrients to the first crop, also provides substantial residual effect of unutilized nutrients on the succeeding crop (Lalith et al., 2013).

The microorganisms benefited from the presence of diversified organic residues in the soil, due to the utilization of the substrate for increased microbial biomass. Studies has indicated a reduction of the biodiversity of the ecological relations in the soil (Medeiros and Lopes, 2006; Muñoz et al., 2017; Ascari et al., 2018). So too, soil covered with plants is an effective way to suppress weed growth and reduce soil erosion and nutrient leaching while increasing soil organic matter and sustaining long-term soil fertility and crop production (Fageria et al., 2005; Montemurro et al., 2013).

Following on from the points discussed above, the objective of this research was to evaluate the performance of different types of green manures on conventionally used soil.

MATERIALS AND METHODS

The experiment was carried out in the District of Concepción (Paraguay) at geographical coordinates 23º 20' 35.5' latitude south and 57º 11' 47.7' longitude west, 200 m above sea level. The soil of the region is characterized by a fine and weakly structured loamy sandy texture (López et al., 1995). To determine the chemical characteristics of the soil, 40 sub-samples of the litter from 0 to 0.20 m depth were collected in various parts of the experiment area with the following results, pH $CaCl_2$ = 5.56; P = 6.31 mg dm^{-3}; K = 0.24 $cmol_c$ dm^{-3}; Ca = 2.88 $cmol_c$ dm^{-3}; Mg = 0.41 $cmol_c$ dm^{-3}; Al = 0.00 $cmol_c$ dm^{-3}; H+Al = 2.21 $cmol_c$ dm^{-3}; CIC = 5.75 $cmol_c$ dm^{-3};V = 61.52 % e MO = 1.01%. The region has a climate that is transitional between a Mediterranean type climate and a humid climate with mean annual temperature of 24°C and mean annual rainfall of 1000 to 1200 mm. The months of most rainfall are December and January, and those of least rainfall are June, July and August (DINAC, 2016). A Randomised Complete Block Design (RCBD) was used, with 4 treatments and 5 repetitions. The treatments consisted of 4 green manure crops of the fabaceae family: T1, *M. pruriens*; T2, *C. ensiformis*; T3, *D. lablad* and T4, *C. cajan*. The experimental units consisted of plots measuring 100 m in which the treatments were implanted. There was a 2 m walkway between the experimental units. The *M. pruriens* and *D. lablad* had a density of 0.50 m between plants and 1 m between rows, holding approximately 40,000 Pl/ha^{-1}. The *C. ensiformis* had a density of 0.30 m between plants and 0.50 m between rows, containing around 66, 600 Pl ha^{-1}. The *C. cajan* had a density of 0.50 m between rows and 18 plants per metre, with approximately 140.000 Pl ha^{-1}. The measurement of each experimental unit was done with a 50-m measuring tape. The total measurements of the sides were of a width of 50 mand a length of 62 mm (50 x 62), representing a total area of 3100 m^2. In accordance with the experimental design, the distribution of each treatment within the experimental area was done at random. The areas that were to be used for the cultivation of the green manures were then cleared. This clearing consisted of one passing-over with a brush cutter; the plant debris was left as a coverage on the ground. Soil samples were then taken in order to ascertain the current state of the soil. The methodology consisted of taking a sample of 30-cm depth from each experimental unit using a spade. The samples were subsequently packaged and sent to a laboratory. After the preparation of the experimental units and the taking of soil samples, the planting of the different crops was carried out. This was done with a manual seed drill; 2 to 3 seeds were deposited in each hole in accordance with the parameters established for each species. During the growth and development of the crops that were used as green manure, relevant measures of care were taken as needed. Just one weeding was carried out 8 days after the emergence of the seedlings using a hoe. In regards to the availability of water, this was provided by rainfall during the crop cycle. The materials used for the collection of data were: pens, markers, a notebook, plastic bags, a bucket, bags, machetes, spades, hoes and scales. In order to determine the increase in growth (%), the height of the plants was evaluated at 30, 60 and 90 DAE (days after emergence). Six plants were evaluated per experimental unit using a tape measure showing centimetres, using the equation:

$$\text{Increase in growth (\%)} = \frac{initial\ height}{final\ height} x100$$

In order to determine the green mass of weeds, a 1 m^2 wooden frame was used at 60 and 90 DAE to determine the area in which measurements were to be taken. Subsequently, machetes were used to cut the weeds at ground level within the selected area. Then, the weeds from each experimental unit were gathered in bags so that they could later be weighed. To determine the production of green mass and dry mass, a 2 m^2 area was measured in each experimental unit by throwing the 1 m^2 wooden frame at random two times. Machetes were used to cut the plants found within the area and these plants were then collected in bags to be weighed using the scales. The results were extrapolated for one hectare. The green mass that was gathered was dried by placing it in the sun on tarpaulins for 15 days until a constant weight was achieved. All measurements were carried out following the procedures described by (Berlingeri, 2008). The values that were obtained for each treatment were submitted to an analysis of variance ANOVA. For each of the measurements carried out, and where significant effects were observed, comparisons were made using the Tukey Test at the 5% level of probability.

RESULTS AND DISCUSSION

Increase in growth

In Table 1, the percentage increase of height between

Table 1. Comparison of averages of the percentage growth increase of *Mucuna pruriens, Canavalia ensiformis, Dolichos lablad* and *Cajanus cajan* at days after emergence (DAE).

Treatments	Growth increase (%)	
	30 to 60 DAE	60 to 90 DAE
Mucuna pruriens (T1)	30.6b	40.3a
Canavalia ensiformis (T2)	45.4b	18.1b
Dolichos lablad (T3)	70.6a	17.3b
Cajanus cajan (T4)	40.6b	33.3a
LSD	15.1	13.7
CV (%)	17.1	26.78
OA	46.82	27.2

Averages followed by the same letter are shown as different by the Tukey Test at the 5% level of probability. LSD, Least significant difference; CV, coefficient of variation; OA, overall average.

measuring periods can be observed. Highly significant differences are seen between the treatments. In the first period, T3 had the highest percentage of growth with an increase of 70.6%; this is statistically superior to the other In the second period, a high significant difference was observed. T1 and T4 are statistically equal; these two treatments showed the highest percentage of growth, with 40.3 and 33.3% respectively. T2 and T3 were equal. A minimal difference of 13.7%, a coefficient of variation of 26.78% and overall average of 27.2% were seen. It should be mentioned that the height obtained by each of the species that were studied varied during the two measurement periods as some species have different growth habits. The legume that showed least height increase during the second period was the *D. lablad* (17.3%). This is because at 70 DAE, it began to develop flowers, practically paralysing vegetative growth. Furthermore, it was seen to be affected by the intense cold and frosts. It was observed to be more sensitive than the *M. pruriens*, many of the plants were partially burnt, which led to them not reaching a suitable size. Carballo (2000) describes *C. cajan* reaching a height of 145 cm at 80 DAE, which is superior to that which was obtained in the present study: an average height of 119.5 cm was recorded at 90 DAE. This is because this study was carried out under different climatic conditions, which included adverse climatic conditions that directly intervened in the vegetative development of the plants. García (2002), in a study of the cycle and the biomass productivity of species of creeping and semi-creeping legumes (*D. lablad, Canavalia ensiformis* and *M. pruriens*) in sandy soils, found that *M. pruriens* had a length of 110.5 cm at 60 DAE and 190 cm at 100 DAE, a height increase of 42%. This coincides with this study: the *M. pruriens* showed higher growth than the other treatments in the second period of evaluation from 60 to 90 DAE, obtaining a percentage of growth of 40.3%. Considering that in this study climatic conditions were unfavourable in the first period of evaluation, abundant growth of the *M. pruriens* was not seen; according to treatments. T1, T2 and T4 are statistically equal. A minimum significant difference of 15.1%, a variation coefficient of 17.1% and an overall average of 46.82% were recorded for the first evaluation period. García (2002), it is considered the most aggressive of the species that were evaluated.

Green mass of weeds

Table 2 shows the green mass of weeds in the different treatments. It can be seen that at 60 DAE, there were no significant differences between the treatments. All the treatments were statistically equal, but it can be appreciated that T1 has less green mass with 3.1 mg ha^{-1}. The overall average was 4.5 mg ha^{-1}; the least significant difference was 2.6 mg ha^{-1} and there is a coefficient of variation of 30.52%. It can be observed that at 90 DAE, there are highly significant differences between the treatments, with the lowest incidence of weeds in T4 with 1.4 mg ha^{-1}. The other treatments T1, T2 and T3 were statistically equal, with a least significant difference of 1.2 mg ha^{-1}, and a coefficient of variation of 28.24%. In Table 3, the percentage decrease of weeds (green mass) can be seen from 60 to 90 DAE in the different treatments. T4 shows the largest decrease (70.8%), followed by T2 with a percentage decrease of 57.8%.

Uribe et al. (2000) considered that treatments with legumes produce positive effects for the reduction of aerial biomass of weeds. Working with *C. ensiformis* and *M. pruriens,* they achieved a low level of production of weed biomass; these crops were efficient at decreasing the proliferation of weeds, suppressing 52% of the weeds from 80 to 110 DAE. This shows that they can be used as a biological method to control weeds. In correlation with the present study, the *C. ensiformis* from 60 to 90 DAE is better than the *M. pruriens* in regards to the reduction of weed green mass, which is reduced by 57.8%. This is due to the density that was employed, as it produced a

Table 2. Comparison of averages for the measurement of foliage of weeds of *Mucuna pruriens, Canavalia ensiformis, Dolichos lablad* and *Cajanus cajan* at days after emergence (DAE).

Treatment	Green mass of weeds (Mg ha^{-1})		Reduction of weeds (%)
	60 DAE (ns)	90 DAE (**)	60 to 90 DAE (**)
Mucuna pruriens (T1)	3.1	2.5 b	19.4c
Canavalia ensiformis (T2)	4.5	1.9ab	57.8ab
Dolichos lablad (T3)	5.6	2.9b	48.2b
Cajanus cajan (T4)	4.8	1.4a	70.8a
LSD	2.6	1.2	18.4
CV (%)	30.52	28.24	20.32
MG	4.5	2.2	48.2

Averages followed by the same letter are shown as different by the Tukey Test at the 5% level of probability. LSD, Least significant difference; CV, coefficient of variation; OA, overall average.

Table 3. Comparison of averages for the measurement of green mass and dry mass of *Mucuna pruriens, Canavalia ensiformis, Dolichos lablad* and *Cajanus cajan* at days after emergence (DAE).

Treatments	Green mass (**)	Dry mass (**)	Percentage of DM (**)
	mg ha^{-1}		
Mucuna pruriens (T1)	19.9b	4.02b	20.2b
Canavalia ensiformis (T2)	27.6a	6.60a	23.9b
Dolichos lablad (T3)	17.6b	4.3b	24.4b
Cajanus cajan (T4)	19.5b	7.06a	36.2a
LSD	5.5	1.8	7.8
CV (%)	13.93	17.87	15.5
MG	20.9	5.5	26.9

Averages followed by the same letter are shown as different by the Tukey Test at the 5% level of probability. LSD, Least significant difference; CV, coefficient of variation; OA, overall average.

quicker covering of the soil, which caused competition between weeds and consequent reduction. It can be seen that at 90 DAE, treatments T1, T2 and T3 are statistically equal, however, only T1 and T3 are superior to T4. Sanclemente (2009) evaluated some benefits of the use of coverings of *M. pruriens* and *C. ensiformis* for a maize crop. Results showed that there was a 74.4 and 72.9% maximum suppression of the amount of weeds for the treatments with *M. pruriens* and *C. ensiformis* respectively. The species of weeds that were most reduced by the coverings were *Cynodon dactylon* and *Brachiaria*. The most dominant species during the experiment was *Cyperus rotundum*. In comparison, during the present study with *M. pruriens* and *C. ensiformis*, a weed reduction of 19.4 to 57.8% was achieved at 60 to 90 DAE due to the aggressiveness of these weeds and to the fact that weeding was only carried out at 10 DAE. However, in this study the green mass of weed species was also reduced; *C. dactylon* and *C. rotundum* were the predominant species in the experimental area. Similarly, Rubio, using *C. ensiformis*, *M. pruriens* and *D. lablad* for an investigation on weed control, states that on comparing populations of *C. rotundum* at the end of the study, significant differences between the treatments were not found. All of the treatments had reduced the population by 85% at 109 days after sowing. In the present study, there were significant differences at 90 DAE between the different species of green manures for the reduction of weed populations; the results are not uniform due to the crop density that was employed and to the fact that development of the different crops was not uniform. Studies carried out by Sevilla (2008) indicate that at 30 and 45 days, there was no decrease in grass, broadleaf and *Cyperus* populations. This is because the coverings did not provide uniform cover, therefore, relevant data on the reduction of weed populations was not found. However, Moreira et al. (2013) was able to observe differences in weed populations at 90 days, when the crops cover the entire cultivated area. The present study's results coincide with this: at 60 DAE the treatments were equal, but at 90 DAE reduction and differences in the amount of weed green mass could be observed in the different treatments. This is due to the cultivated area being completely covered by the green manures.

Green mass and dry mass of green manures

In Table 3, the production of foliage and dry mass of each treatment can be observed. There are highly significant differences between the treatments both in respect to production of green mass and dry mass. It can be seen that the biggest production of green mass was obtained by T2 with 27.6 mg ha^{-1}. Treatments T1, T2 and T4 were statistically equal. There are highly significant differences between the treatments in respect to the production of dry mass. T2 and T4 were statistically equal and T4 was higher than the other treatments with a production of 7.06 mg ha^{-1}. T1 had the lowest production of dry mass with only 4.02 mg ha^{-1}.

According to Jiménez et al. (2005), sowing density does not influence the production of dry biomass of *C. cajan*, and results achieved indicate that factors like the physical-chemical properties of the soil, the genetics of the plants and the management of the crop, amongst other factors, determine the level of production. A production of 7.65 mg ha^{-1} of dry mass of *C. cajan* was observed; a density of 172,000 plants hectare was used. In comparison, in the present study, a production of dry material of 7.06 mg ha^{-1} was seen. A density of approximately 66,600 planta hectare was employed, which is lower than the density used by Jiménez et al. (2005). As a result, it is shown that population density does not influence the production of green mass and dry mass in the cultivation of *C. cajan*, and that, as mentioned, other factors are responsible. The broad adaptability of *C. ensiformis* and *M. pruriens* to diverse climatic conditions allowed good development during the cycle. The samples that were taken indicated that the *C. ensiformis* produced 10.8 Mg ha of dry biomass whilst the *M. pruriens* produced 7.5 mg ha^{-1} (Barreto et al., 2002). Equally, in the present study, the *C. ensiformis* showed abundant growth in the first period (Table 2) in spite of climatic conditions during the cycle. A production of 27.6 mg ha^{-1} foliage was seen, which was more than the other species. However, it had a dry mass production of 6.6 Mg ha^{-1}. This was less than the *C. cajan*, which had the highest production of dry mass at 7.06 Mg ha^{-1}: this dry mass represents 36.2% of the green mass that was recorded. In comparison, the *M. pruriens* had a green mass production of 19.9 Mg ha^{-1} and a dry mass production of 4.02 mg ha^{-1}, which is equivalent to 21.4%; this is less than the *C. cajan*. This difference is due to the fact that *C. cajan* has woodier stalks and a lower water content. Rubio (2006) indicates in a study that *C. ensiformis* was the crop that produced most dry mass: it produced 5.5 mg ha^{-1} of dry mass and 30 Mg ha^{-1} of green mass. This is reflected in the closure speed of the crop, which was 70-80 days after sowing. In comparison, *D. lablad* and *M. pruriens* are more aggressive crops, which start to close at 40-50 days after sowing and close entirely at 60-70 days. In the present study, the *C. ensiformis* is g ha^{-1} respectively; these results are higher than those obtained by Rubio (2006). This is due to the fact that *C. ensiformis* displayed higher height increase during the first period. This height increase was larger than that of the other species of green manures, due to the fact that the *M. pruriens*, *D. lablad* and *C. cajan* were affected by the weather.

The longer legumes are left growing, the larger the amount of dry mass accumulated (Moreira et al., 2013). This can be observed within the present evaluation, which only lasted until 90 days after emergence due to the fact that the species began to enter their flowering stage; a larger accumulation of dry mass could be obtained from all the species. Ferreira et al. (2016) recorded a result regarding the production of dry mass at 120 DAE: 9.57 mg ha^{-1} for *C. ensiformis*, 10.28 mg ha^{-1} for *M. pruriens* and production of 10.12 mg ha^{-1} for *C. cajan*. These results are higher than those gathered in the present study, which lasted 90 days; above affirmation made by Moreira et al. (2013) which can be seen as the cause of this difference. Martin (2009) obtained a dry mass production of 9.76 mg ha^{-1} for *C. ensiformis*, confirming that the plant grows well during periods of rain and long days, which confirms it to be a good green manure. This is also shown in the present study, in which good rainfall was had during the cycles of the different species; *C. ensiformis* responded well to these conditions in spite of the very low temperatures and short days. *C. cajan* also obtained a good dry mass production of 7.06 mg ha^{-1}

Conclusions

In comparison with *C. ensiformis*, the use of *M. pruriens, D. lablad*, and *C. cajan* favours the production of vegetable coverage to a lesser extent. *C. ensiformis* showed the best coverage, giving constant coverage throughout the year as a companion plant and/or within a crop rotation system.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

REFERENCES

Ascari JP, Vieira D, Nogueira Mendes IR, Foschiera MV, Sbruzzi Prieto R, Moreira BARBOZA WH, KRAUSE W ,SUSSUMU MATSUMOTO L (2018). Quality of Soil in the function of biological fertilization and plant covering. African Journal of Agricultural Research 13(15):733-741.

Barreto H, Sain G, Bolaños J, Raun W (2002). Efecto de dosisde urea-n en el rendimiento del maíz bajo un sistema de rotación con leguminosas de cobertura. Programa Regional de Maíz para Centro América y El Caribe. Agronomía Mesoamericana 5:88-95.

Berlingeri C (2008). Evaluacion de cinco leguminosas en barbecho mejorado para el control de malezas en la planicie del río Motatán. Agronomía Tropical 58(2):119.

Carballo J (2000). Evaluación de la producción de biomasa en base verde kg/ha bajo tres densidades de siembra. Catastro e inventario de recursos naturales de Nicaragua. http://cenida.una.edu.ni/TESIS/TNF01A481.PDF

Direccion Nacional de Aeronautica Civil (DINAC) (2016). Direccion de Meteorologia e Hidrologia de la Direccion Nacional de Aeronautica Civil. https://www.meteorologia.gov.py/index.php

Fageria NK, Baligar VC, Bailey BA (2005). Role of cover crops in improving soil and row crop productivity. Communications in Soil Science and Plant Analysis 36:2733-2757.

Ferreira E, Stone, Partelli A Didonet (2016). Productividad del frijol común influenciada por plantas de cobertura y sistemas de manejo del suelo. Revista Brasileira de Engenharia Agrícola e Ambiental 15(7):695-701.

Garcia L (2002). Introdução e avaliação de leguminosas para adubação verde em solos arenosos de tabuleiros costeiros do Piauí. Ver. de la Facultad de Agronomía 28:93-103.

Guzman IG, Alonso MA (2008). Buenas practicas en produccion ecologica. Uso de abonos verdes. Centro de investigación y Formacion en Agricultura Ecologica y Desarrollo Rural. Santa Fe-Granada. http://www.agroecologia.net/recursos/publicaciones/bppe/Uso_de_Abonos_Verdes_tcm7-187426.pdf

Jimenez SAM, Farfan VF, Morales LCS (2005). Biomasa seca y contenido de nutrientes de Cajanus cajan, Crotalaria juncea y Tephorosia candida, empleadas como abonos verdes en cafetales. Cenicafe 56(2):93-109.

Lalith Kannan R, Dhivya M, Abinaya, Lekshmi D, Krishna L, Krishnakumar S (2013). Effect of Integrated Nutrient Management on Soil Fertility and Productivity in Maize. Bulletin of Environment, Pharmacology and Life Sciences 2(8):61-67.

Martín M (2009). Manejo de la inoculación micorrízica arbuscular, a Canavalia ensiformis y la fertilización nitrogenada en plantas de maíz (*Zea mays*) cultivadas sobre suelos Ferralíticos Rojos de La Habana. Doctoral thesis. http://agris.fao.org/agris-search/search.do?recordID=CU2010400099

Medeiros MB, Lopes JS (2006). Biofertilizantes líquidos e sustentabilidade agrícola. Bahia Agrícola 7(3):24-26.

Montemurro F, Fiore A, Campanelli G, Tittarelli F, Ledda L, Canali S (2013). Organic Fertilization, Green Manure, and Vetch Mulch to Improve Organic Zucchini Yield and Quality. Hortscience 48(8):1027-1033.

Moreira V, Pereira A, Guerra J. Guedes R, Costa J (2013). Produção de biomassa de guandu em função de diferentes densidades e espaçamentos entre sulcos de plantio. Seropédica: EMBRAPA AGROBIOLOGIA. 5 p. (Comunicado Técnico, 57).

Muñoz K, Buchmann C, Meyer M, Schmidt-Heydt M, Steinmetz Z, Diehl D, Thiele-Bruhn S, Schaumann GE (2017). Physicochemical and microbial soil quality indicators as affected by the agricultural management system in strawberry cultivation using straw or black polyethylene mulching. Applied Soil Ecology 1:36-44

Ramírez M, Andrade Limas E, Rivera Ortiz P, Romero Díaz A (2011). Degradación de suelos por actividades antrópicas en el norte de Tamaulipas, MÉXICO. University of Murcia, Spain. http://revistas.um.es/geografia/article/view/143451

Rubio J (2006). Efecto de Canavalia, Dolichos, Mucuna y Cowpea en la población de coyolillo (Cyperus rotundus), insectos, nematodos y fertilidad del suelo. Tesis Ing. Agr. El Zamorano, Honduras, Escuela Agrícola Panamericana P. 22.

Sanclemente O (2009). Efecto del Cultivo de Cobertura: Mucuna pruriens, en algunas propiedades físicas, químicas y biológicas de un suelo Typic Happlustalfs, cultivado con maíz (Zea mays L.) en la zona de ladera del Municipio de Palmira, Valle. Palmira. Colombia. National University of Colombia 6 p.

Sevilla F (2008). Efecto de Dolichos lablab, Mucuna pruriens, Vigna senensis y Sorghum bicolor en el manejo de coyolillo (Cyperus rotundus) y nematodos (Meloidogyne sp.). Tesis Ing. Agro. Zamorano, Honduras, Escuela Agrícola Panamericana 13 p.

Uribe S, Nicolas NF, Lopez E, Camacho R, Turrent A (2000). Desarrollo del cultivo de frijol en sistemas de producción sostenibles. San Andrés Tuxtla, Veracruz, México. http://www.mag.go.cr/rev_meso/v10n02_059.pdf

Vol. 13(36), pp. 1880-1887, 6 September, 2018
DOI: 10.5897/AJAR2018.13279
Article Number: 26DDDA758421
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Response of potato to different soils and fecal matter fertilizers

Kevin N. Juma[1], Lenah Nakhone[1*], Amos A. O. Musandu[1], Samuel Nyalala[1], Joshua O. Ogendo[1] and Lawrence Kimaru[2]

[1]Department of Crops, Horticulture and Soils, Egerton University, P. O. Box 536-20115 Egerton, Kenya.
[2]SNV Netherlands Development Organisation P. O. Box 30776-00100 Nairobi, Kenya.

Received 29 May, 2018; Accepted 19 July, 2018

Potato (*Solanum tuberosum* L.) is an important food and cash crop in Kenya. However, its production has declined over the years due to extensive nutrient mining without adequate replacement. A study was conducted to evaluate the response of potato grown under three soil types (Planosol, Andosol and Acrisol) using three fecal matter fertilizers (FMFs). This included vermicompost, normal compost and dried sludge. In addition, common fertilizer (urea and cow manure) was also used. Two greenhouse trials were laid out in a randomized complete block design with four replicates per treatment. Data collected on soil nutrient status, plant growth and yield variables were subjected to analysis of variance using Statistical Analysis Software v.9.1 and treatment means separated using Tukey's test. Results showed that fecal matter fertilizers (FMF) , vermicompost and dried sludge, were equally effective in increasing (39.2-46.5%) the potato growth compared to untreated control. Fecal matter fertilizers also contributed to high yields, where vermicompost produced (12.3 t ha^{-1}) 3 times more than untreated control (4.2 t ha^{-1}) but the difference was not significant at P≤0.05 from urea, normal compost and sludge. The interaction between fertilizers and soil types was not significant at P≤0.05. Fecal matter fertilizers are thus ecologically viable alternative source of mineral nutrients for sustainable potato production.

Key words: Acrisol, andosol, planosol, *Solanum tuberosum,* sludge, vermicompost.

INTRODUCTION

Potato is the second most important food and cash crop after maize in Kenya. It is grown both as a horticultural crop and a food security crop. In Kenya, potato plays an important role as a food staple among small scale farmers and also contributes to poverty alleviation through income generation. Approximately one million farmers grow potato in Kenya, while over 2.5 million Kenyans are employed along the potato value chain either directly or indirectly (Okello et al., 2017). Most farmers in Kenya dedicate more than a third of their arable land to the crop (Peter et al., 2009). Despite its importance, potato production is constrained by soil degradation, lack of quality seeds, as well as pest and disease management among other factors (Were et al.,

*Corresponding author. E-mail: lenahnakhone@gmail.com.

2013).

Soil fertility and crop management practices are not only key components of sustainable crop production in potato based cropping systems but also decisive factors for increased productivity and crop quality (Scott et al., 2000). Soil fertility management also stimulates microbial soil life and decomposition processes, which in turn reduce the incidence of soil and seed borne diseases such as bacterial wilt. According to Amon et al. (2014), degradation of the soil causes up to 8% decline in potato yields. Apart from soil degradation, rainfall is the only source of water for potato production in Kenya, hence the main source of variations in yields. It is possible that the problem of low soil pH has led to imbalances in nutrient content leading to further decline of potato yields (Janssens et al., 2013). The Fecal matter fertilizers (FMFs) can be used to replenish nutrients in the soil since they contain up to 0.7% N (Nitrogen) as a percentage of wet weight (Rose et al., 2015) which is about 5 to 11 g per day (Hakan et al., 2015); where waste water from sludge has been used for irrigation it raised N, P, and K contents in potato plants and tubers. Irrigation by wastewater could reduce the fertilizer requirement of potato by 10-15%. About 11% N, 25% P (Phosphorous) and 21% K (Potassium) can also be recycled from feces (Vinnerås et al., 2006). Furthermore, approximately 80% of N, 50% of P and nearly 60% of K are found in household waste water, which can be recycled so that these nutrients can be availed for crop use. The objective of this study is to evaluate the effect of fecal matter fertilizers on potato crop grown under different soil types, Andosols, Planosols and Acrisols.

The selected soils are the major three soil types found in abundance in Nakuru County (FAO, 2006). Acrisols are soils that originate from variety of parent materials ranging from weathering of acid rocks for highly weathered clays that are undergoing further degradation and are usually found in old land surfaces that are hilly with natural vegetation. Andosol originate from volcanic glasses or other silicate-rich material and is dominant in undulating to mountainous, humid, and arctic to tropical regions with an extensive range of different vegetation. Finally, Planosols are soils that have a coarse-textured surface horizon with a finer textured subsoil that are prone to logging in flat lands formed from clayey alluvial and colluvial deposits. Furthermore, they contain light forest or grass Vegetation (Jaetzold et al., 1982). This research is aimed at using feacal matter fertilizers (FMFs) to help in making these soils productive by improving their physical, chemical and biological properties.

MATERIALS AND METHODS

Greenhouse experiments were set up at the Domestic Water Treatment Plant (0°19'22"N and 36°3'46"E) of Nakuru Water and Sanitation Services Company (NAWASSCO) located in Nakuru National Park, Kenya. The site lies in Lower Highland III (LH_3) Agro Ecological Zone with an altitude of 1850 m.a.s.l (Jaetzold et al., 2012). The average maximum and minimum temperatures range from 19 to 22 and 5 to 8°C, respectively. The annual rainfall ranges from 800 to 900 mm and the soils are predominantly well drained, deep to very deep dark brown to grayish brown friable and smeary clay loam, with thick humic topsoil (Mollic Andosols) (Mainuri and Owino, 2013).

Preparation of fecal matter based fertilizer products

Composting materials (composite market waste) were collected from the Municipal Market, Nakuru town and NAWASSCO waste water treatment plant (sludge). Proper sorting was done to ensure only degradable materials were composted and coarse/ large materials like banana stalks were chopped into smaller pieces. The pieces were then placed in the in wooden boxes and mixed in the ratio of 3:1 (market waste: sludge) in the greenhouse. For normal compost, the materials were allowed to compost for 5 months with weekly turning and addition of water as maintenance practices. On the other hand vermicompost, worms were introduced after one month and favorable conditions (Temperature: 15-25°C, Moisture: 75% and pH: 5.7) for their survival maintained. Finally, the vermicompost was maintained in aerobic environment. Dry sludge was prepared by sun drying the sludge directly on drying beds lined with black plastic sheet in a greenhouse at 40-60°C for one month.

Collection and characterization of test soils

Three different soils, representing Planosol, Acrisol and Andosol, were collected from Nessuit (Latitude: -0°23'25.99"S, Longitude: 35°52'52.32"E), Egerton University (Latitude: 0°22'11.0"S, Longitude: 35°55'58.0"E) and Molo (Latitude: 0.2488°S, Longitude: 35.7324°E), respectively in Nakuru County, Kenya. The soils used are the dominant soils in Nakuru County and some parts of the central Highlands of Kenya where potato crop is extensively grown. The sites where the soils were collected were cleared to remove vegetation cover and the soils were dug to a depth of 30 cm. Each soil sample comprised of a combination of the top soil and the subsoil. The soils were then put into sample bags (size: 240 kg soil) per soil type and was enough for the entire experiment. Characterization of the soil was partly done in the field and the laboratory where samples were taken for analysis to determine the physical and chemical properties. The properties analyzed were pH (electrometric), N (Kjeidahl), P (Mehlich), K (Flame photometer) and bulk density (core).

Nitrogen (Kjeldahl method)

A soil sample weighing 0.3 g was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, Se and $CuSO_4$. The temperatures in the heating block was maintained at 360°C for two hours after which the samples were let to cool and transferred to 50 ml volumetric flasks and the volume made to the mark. It was then allowed to settle and 5ml of the aliquot was put in to the distillation bottle where 10ml of 40% NaOH was added. It was then steam distilled into 5ml 1% Boric acid containing 4 drops of mixed indicator for 2 min, from the time the indicator turned green. The distillate was titrated using HCl and the end point was reached when the indicator turned green through grey to definite pink. A blank experiment was prepared using the same procedure (Kirk, 1950).

Bulk density (Core method)

A core ring of 5 cm diameter with known weight (W1) and volume

Table 1. Chemical and physical properties (Mean ±SE) of three soil types.

Soil type	pH	Chemical properties		Physical property	
		N (%)	P (mg/kg)	K (mg/kg)	BD (g cm^{-3})
Andosol	6.23±0.07	0.19±0.08	43.0±0.61	68.2±1.25	1.26±0.04
Planosol	6.72±0.1	0.23±0.03	35.0±0.64	62.4±1.02	1.37±0.62
Acrisol	5.75±0.21	0.36±0.02	58.0±0.82	93.5±1.28	1.24±0.07

N= Nitrogen, P= Phosphorus, K= Potassium; BD= Bulk density; Means in a column whose SE values do not overlap are significantly different at α=0.05 by Tukey's HSE test.

Table 2. Nutrient composition (Mean±SE) of test organic fertilizers.

Organic fertilizer	N (%)	P (%)	K (%)
Vermicompost	2.3±0.07	0.4±0.02	0.4±0.06
Normal compost	1.8±0.24	0.3±0.12	0.4±0.03
Sludge	1.5±0.07	0.2±0.04	0.2±0.04
Cow manure	0.6±0.15	0.3±0.08	0.4±0.08

N= Nitrogen, P= Phosphorus, K= Potassium; Means in a column whose SE values do not overlap are significantly different at P≤0.05 by Tukey's HSE test.

(V) was inserted 5cm in the soil. It was the removed from the soil and soil around the core was wiped and trimmed at the bottom and top using a knife. They were then placed in an oven at 105°C for 2 days after which they were allowed to cool and weighed (W2).

Potassium

A soil sample weighing 0.3 g was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, HF and $H_3 BO_3$. The temperatures in the heating block maintained at 360°C for two hours after which the samples were let to cool and transferred to 50 ml volumetric flasks and volume made to the mark. Calibration was done for each element using certified standards. Samples were analysed using Varian spectra AA10 AAS machine.

Phosphorous

0.3 g sample was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, Se and $CuSO_4$. The temperatures in the heating block maintained at 360°C for two hours after which the samples were let to cool and transferred to 50ml volumetric flasks and volume made to the mark. 5 ml of the aliquot was transferred in to the sample bottles with 1 ml of developing colour solution (Ammonium Vanadate and Ammonium Molybdate in the ratio of 1:1). The samples were left to stand for 30 min after which they were transferred to cuvates. Readings (absorbance) were taken using a spectrophotometer at 430 wavelength. Calibration was done using certified standards. The chemical composition of the soils used in the study are presented in Table 1 while the nutrient composition of the FMFs are presented in Table 2.

Experimental design and layout

Two pot experiments were conducted in a plastic greenhouse. The plastic containers (pots), with a size of 10 l, were filled with 10 kg of soil each and a total of 18 pots randomized per block in 4 blocks. The treatments were set up in a Randomized Complete Block Design (RCBD) with factorial arrangement of two factors, soil type and fecal matter fertilizers. The treatments included three levels of soil types (Acrisol, Andosol and Planosol) and three fecal matter fertilizers (vermicompost, normal compost and sludge) and positive inorganic fertilizer control, urea and organic fertilizer cow manure, replicated four times and arranged 30 cm between the pots and 75 cm between the blocks .

Crop establishment

Healthy and sprouted seed potato tubers were sliced into pieces each weighing 25 to 30 g and having 2 to 3 eyes (buds). Every pot was planted with one sliced piece of tuber at a depth of 5 cm. The various amendments were applied at different rates as follows: vermicompost, 3.9 t/ha; normal compost, 4.9 t/ha; Urea, 0.2 t/ha; dried sludge, 6 t/ha; and cow manure 15 t/ha.

Data collection

Data were collected on a weekly basis for four weeks after germination on growth variables. The number of branches was determined by counting well-developed branches with leaves. Plant height measurements (cm) were taken from the base of each crop to the top of the main plant stem using a ruler. Numbers of leaves were counted on well-developed branches and yield was obtained by weighing (grams) the tubers using electronic balance (SF-400) and later converted to t ha^{-1}.

Data analysis

Data were subjected to analysis of variance (ANOVA) using Proc GLM, SAS software v.9.1 (*SAS INC*., 2001). Where ANOVA revealed existence of significant differences among treatments, means were separated using Tukey's HSD test at P≤0.05.

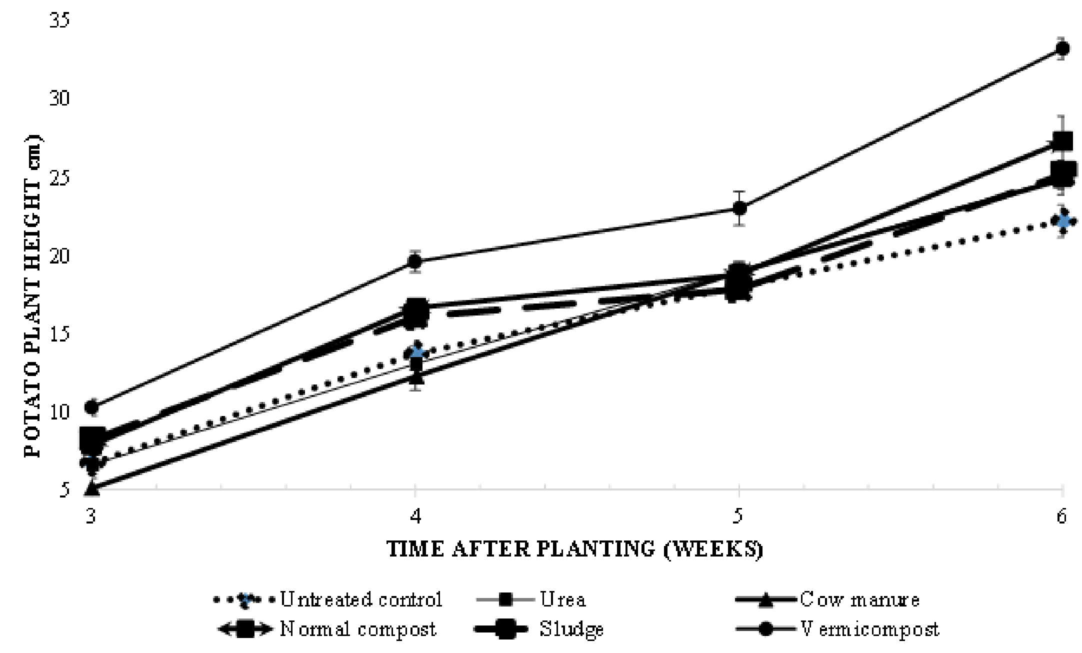

Figure 1. Potato plant height (Mean ± SE) response to fecal matter fertilizer under Andosols.

RESULTS AND DISCUSSION

Effect of fecal matter fertilizers (FMFs) on potato height

Under Andosol soil, results showed that vermicompost produced significantly ($P \leq 0.05$) better potato height response compared to other fertilizers at all the growth stages. The potato crop had same level of height response to normal compost and sludge at all growth stages. The other treatments, urea, cow manure and untreated control equally produced the lowest height response and there were no differences during the period of week 3, 4 and 5 (Figure 1).

According to figures obtained from Planosol, however, vermicompost, normal compost, cow manure and urea treatments were different during week 3, 5 and 6. Untreated control had the lowest performance in all the growth stages (Figure 2). The FMFs produced comparable height responses under Acrisol soil in which sludge, urea and vermicompost recording equally taller plants at all the growth stages. The latter fertilizers produced results that were superior to cow manure, normal compost, and untreated control (Figure 3). FMFs vermicompost, normal compost and sludge were able to supply enough nitrogen that contributed significantly to potato plant height under Andosol and Acrisol. This is because they have the benefit of being slower-acting and gentler than urea as a chemical fertilizer. These products were in a form which did not allow them to be absorbed immediately by plants but had to be broken down first by soil bacteria and fungi into forms that plants can absorb which is in agreement with the findings of Borah et al. (2007). This means that, unlike in inorganic fertilizer, they were not easily leached, and that the potato crop got the benefit of nutrients for growth more evenly over a period of time during the vegetative stage. When it came to Planosol, the response was low; although the performance of sludge, vermicompost, cow manure and urea had no significant difference in week 3, 5 and 6. This is attributed to the soil characteristic of Planosol that restricts root development, thus low water and nutrient absorption.

Effect of FMF on a number of branches and leaves of potato

Results showed clear plant age-dependent increase in a number of branches and leaves in response to fecal matter fertilizers application. At the end-point response, 6 WAP, the normal compost, sludge and vermicompost fertilizer applications in a potato crop, under the Andosol soil, produced significantly ($P \leq 0.05$) 5.8 to 24.0% more number of branches compared to the untreated control. Similarly potato grown under Acrisol produced 22.6 to 38.7% number of branches more compared to the untreated control (Table 3). The cow manure, urea and the untreated control equally recorded the lowest number of branches and leaves over the growth period. Furthermore, results showed significant ($P \leq 0.05$) age and soil type-dependent response of a number of plant

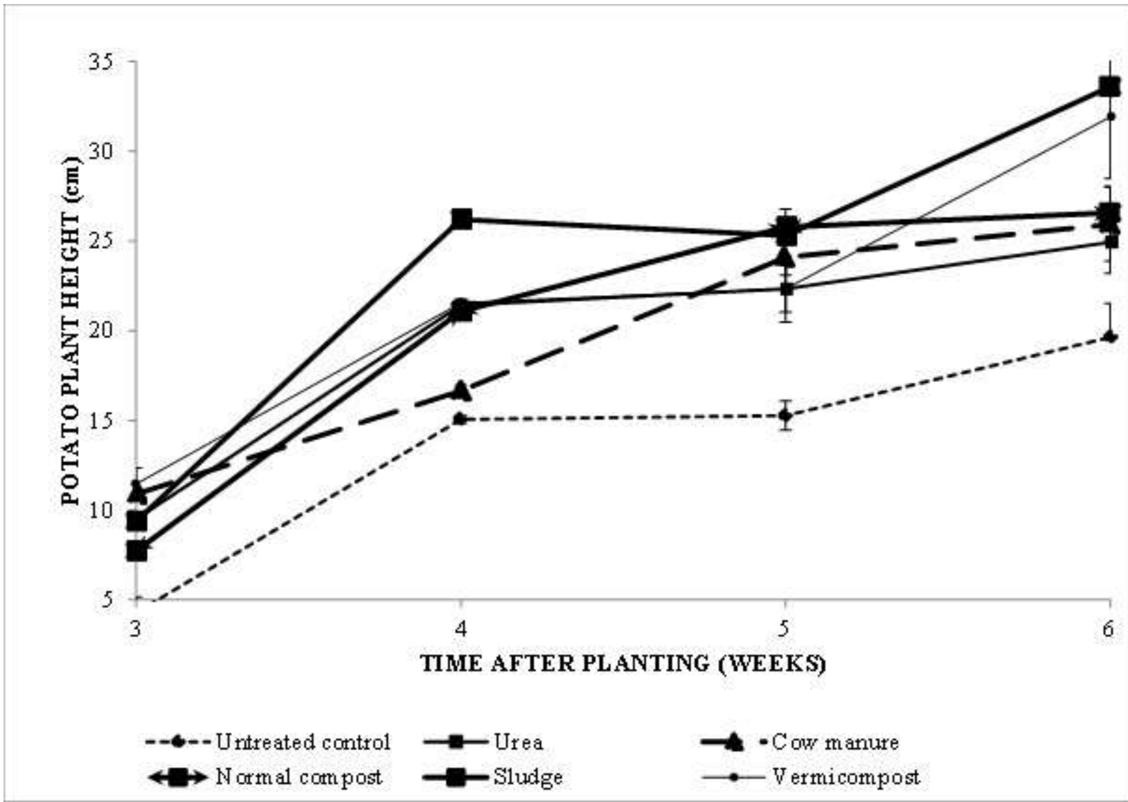

Figure 2. Potato plant height (Mean ± SD) response to fecal matter fertilizer under planosol.

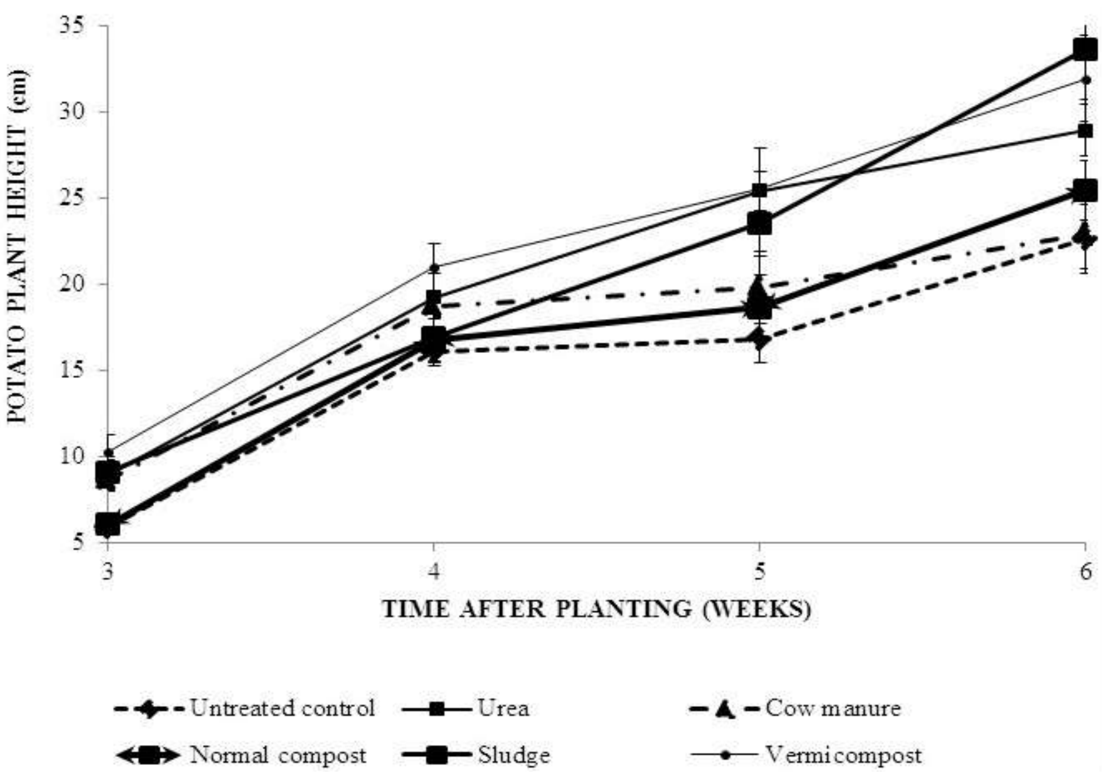

Figure 3. Potato plant height (Mean ± SD) response to fecal matter fertilizer under acrisol.

Table 3. Growth response of potato to faecal matter fertilizers under different soil types.

WAP fertilizers	Andosols		Planosols		Acrisol	
	NB	NL	NB	NL	NB	NL
Untreated control	2.9±0.1	10.7±0.9	4.6±0.4	9.9±0.4	3.0±0.6	13.4±0.3
Urea	3.5±0.7	19.0±0.3	3.3±0.3	26.3±0.6	3.0±0.0	18.8±0.7
Cow manure	4.0±0.0	12.0±1.0	3±0.1	20.8±0.5	3.5±0.4	17.4±0.6
Normal compost	5.0±0.1	17.6±0.1	3.5±0.1	19.8±0.4	4.0±0.0	19.3±0.7
Sludge	4.3±0.2	22.6±0.2	4.3±0.5	17±0.3	4.0±0.4	17.2±0.5
Vermicompost	5.3±0.3	19.5±0.6	4 ±0.0	17.5±0.4	4.3±0.1	17.0±0.6
Untreated control	4.4±0.1	34.7±0.5	5.2±0.4	30.0±0.3	3.6±0.3	36.2±0.5
Urea	5±1.8	34.0±0.6	4.7±0.6	53.5±0.2	6.0±0.3	57.5±0.4
Cow manure	4.3±0.2	34.5±1.3	4.5±0.3	57.2±0.6	3.7±0.3	57.8±0.6
Normal compost	6.7±0.1	64.3±0.8	6.0±0.4	50.0±0.5	5.7±0.5	55.0±0.6
Sludge	5.3±0.4	62.3±0.8	5.4±0.8	53.5±1.2	5.0±0.1	53.1±0.4
Vermicompost	6.3±0.3	51.5±0.8	6.0±0.4	61.7±0.4	6.3±0.1	50.0±0.4
Untreated control	8.7±0.1	46.9±0.54	7.5±0.1	43.9±0.4	6.7±0.4	67.3±0.5
Urea	6.7±1.8	54.3±0.7	9.3±0.2	79.2±0.8	8.7±0.2	74.4±0.8
Cow manure	6.3±0.5	54.5±1.1	8±0.01	87.8±1.0	7.0±0.4	80.2±0.3
Normal compost	10.7±0.4	69.5±0.6	9.5±0.1	83.6±1.0	9.3±0.3	86.0±1.2
Sludge	8.3±0.1	62.3±0.6	7.5±1.9	65.5±0.8	9.3±1	76.8±0.8
Vermicompost	10.8±0.1	68.2±0.6	10.3±0.1	69±0.7	10.5±0.3	96.2±0.6
Untreated control	10.4±0.1	51.6±0.77	12.6±0.1	46.6±0.7	10.6±0.1	67.8±0.6
Urea	11.8±0.5	60.8±0.4	13.7±0.4	83.3±0.6	14.3±0.3	84±0.6
Cow manure	11.8±0.1	61.8±0.4	9.3±0.6	88±0.4	11.3±0.2	88.5±1.2
Normal compost	12.7±0.4	71±0.3	12.0±0.3	94±0.8	14.7±0.1	86±0.9
Sludge	11±0.4	66.5±0.3	12.6±1.6	72.9±0.7	13.0±0.6	79.4±0.7
Vermicompost	12.9±0.3	68.2±0.4	13±0.8	75.5±0.7	13.5±0.1	101±0.6

NB = Number of branches, NL= Number of leaves, WAP= Weeks after planting; Means in a column whose SE values do not overlap are significantly different at P≤0.05 by Tukey's HSD test.

leaves. At the end-point response, 6 WAP, the normal compost, sludge and vermicompost fertilizer applications produced 28.9-37.6, 56.4-101.8 and 30.5-49.0% more potato leaves under Andosol, Planosol and Acrisol, respectively (Table 3).

For number of branches, the two composts had same ability to supply nitrogen throughout the growth stages and their performance was way better than the other fertilizers applied under Andosol. Andosols are soils that have been cultivated for long and their nutrients have been depleted, especially the level of N, as shown in Table 1. When compost is applied, it improves the soil physical and chemical properties that enabled the fertilizers applied to supply the needed nitrogen to the crop as shown in Table 3. The situation was different under Planosol where low potato response was recorded due to high bulk density (1.37±0.072 g cm^{-3}) across the growth stages (Table 3). Such soils with high bulk density restricted root growth as it increased compaction; thus the crop was not able to absorb water and nutrients from the soil and also tuber growth was limited. This is in agreement with the findings in (Usman et al., 2015). Under Acrisol, the best performance was observed where urea, vermicompost and sludge were applied. This type of soil has properties that favor good water and nutrient absorption and as a result, there was extensive root development. The contribution of cow manure to potato nitrogen supply was limited when compared to FMFs. This is probably due to the slow rate at which cow manure releases nutrients. This is consistent with the findings of Souza et al. (2008), that slower nutrient releasing organic fertilizers hinder growth and production of potato.

For a number of leaves, the performance of all the fertilizers was more or less the same with no significant difference in week 3 under Andosol. This may be due to the stage of the crops where they did not have well developed roots that could absorb nutrients and also the

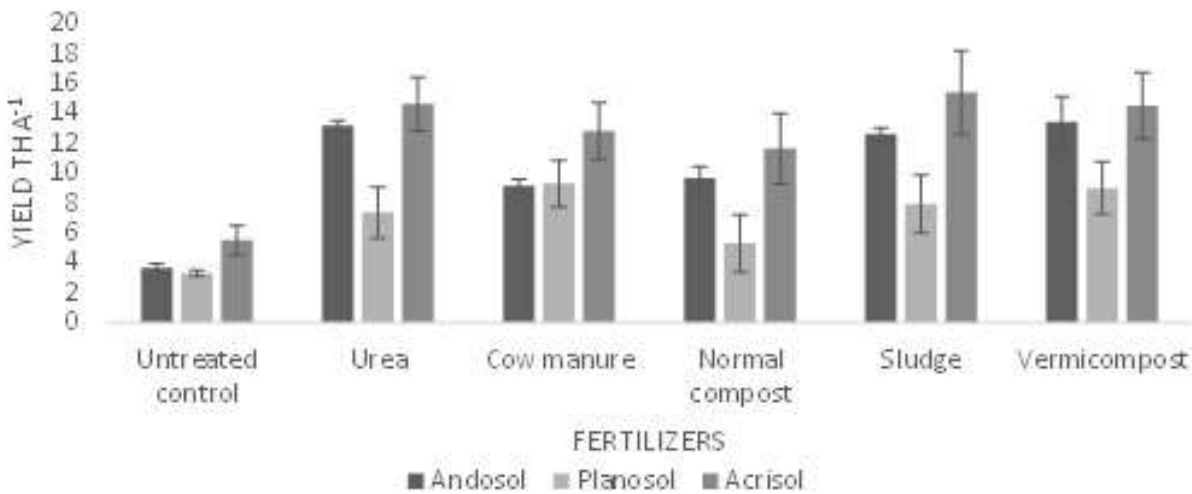

Figure 4. Potato yield (t ha^{-1} Mean ± SD) under different soil types and fecal matter fertilizer application.

products applied. The subsequent weeks exhibited positive response where vermicompost, sludge and normal compost interaction with all the soil types was high as shown in week 4, 5 and 6. This is because vermicompost had two characteristics that favored crop growth; first it had been broken down by worms making it finer and the increase in nutrient content. It is also in organic form, thus it boosts the soil physical properties. Andosols are always fertile soils, but if leached the levels of nutrients decline; consequently leading to use of organic fertilizers. This in line with findings filed in FAO report (2014). There was no significant difference between all the fertilizers across all the growth stages. This means that all the fertilizers applied had same ability to supply nitrogen for vegetative growth.

Effect of FMF on potato yield

Results showed significant (P≤0.05) FMFs and soil type-dependent potato yield responses (Figure 4). Sludge and vermicompost applications equally produced the highest potato yield of 15.4 t ha^{-1} and 14.5 t ha^{-1} under Acrisol soils respectively. These yield levels were comparable to the positive control, urea. Potato crop had the lowest yield response to the different FMFs under the Planosol soils. There was insignificant soil type by FMF interaction effect on potato crop yield. The effect of FMF was felt on yield where fertilizer applied was significant at P≤0.05. The chemical properties of the products applied contributed greatly to increased yield. Vermicompost recorded highest yields of 15.5 t ha^{-1} under Acrisol but the difference was not significant from sludge, urea and cow manure. Acrisols have low levels of nutrients in general, so any addition of nutrients will give a positive response. In this case, acrisols had the highest content of K (93.5 mg/kg) and also N (0.36%). Though acrisols have the ability to fix P, this may have been compensated by substantial amounts in the soil, which may have been taken up by the plant. The low yields from planosols could be attributed to the low nutrient status and poor aeration due to its high clay content. This may have restricted root development. The differences noted among soils were directly proportional to the results obtained from the characterization of the soils in terms of N, P, K and bulk density level. Acrisol had the best properties which meant that it had more ability in making available the nutrients for root absorption. This is explained by the fact that application of nutrients in the soil does not guarantee availability of the same nutrients to the crop due to some processes taking place such as phosphorous fixation. For example, andosols have a tendency to fix phosphorous; any addition from the amendments may be partially fixed in the soil. Suitable soil properties like bulk density of 1 to 1.3g cm^{-3} ensure better tuber formation in the soil, while a high bulk density restricts tuber formation through compaction leading to low yields. These results are in line with the findings of Amara and Mourad (2013).

Among the FMFs, it is evident that vermicompost promoted plant growth and production by 30% more than chemical fertilizers which is in agreement with the findings of Sinha et al., (2010) who found that the use of vermicopmost in production of wheat and corn crops promoted growth by 30 -40% higher as compared to chemical fertilizers. This result may be due to the provision of organic matter by vermicompost to the soil, which helped with the retention of water and nutrients for a healthy root system. Vermicompost has been found to be more superior in protecting the soil and promoting crop growth than any other organic material (Munroe, 2007). The difference in performance demonstrated variation in their capability to constantly supply the required nutrient quantity which they contain when necessary, as shown in Table 2. The effect of interaction between soil types and fertilizers was not significantly different at P≤0.05. This shows that both soil types and fertilizers acted independently to some extent.

Conclusions

Treated Fecal matter fertilizers are an important source of plant nutrients when used in crop production. They improved growth parameters and yield three times more than the untreated control. The performance was also better than cow manure. Potato crop showed positive response to these products particularly vermicompost and their performance was similar to that observed with commonly used inorganic fertilizer urea.

Acrisols amended with sludge had the highest potato yield closely followed by amendment with vermicompost on the same soil. However, planosols had the least potato yield irrespective of the FMFs added.

ACKNOWLEDGMENT

This research was part of a research partnership between Nakuru County Sanitation Program (NCSP)/ Nakuru Water and Sanitation Services Company Ltd. (NAWASSCO) and Egerton University. NCSP is a European Union co-funded program implemented by NAWASSCO with the support of the Nakuru County government, Umande Trust, SNV Netherlands.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Amara DG, Mourad SM (2013). Influence of organic manure on the vegetative growth and tuber production of potato (*Solanum tuberosum* L varspunta) in a Sahara desert region. International Journal of Agriculture and Crop Sciences 22:2724-2731.

Amon MK, Chris S, George M (2014). Analysis of the key challenges facing potato farmers in Oljoro-Orok Division, Kenya. Agricultural Sciences 5:834-838.

Borah MC, Mahanta P, Kakoty SK, Saha UK, Sahasrabudhe AD (2007). Study of quality parameters in vermicomposting. Department of mechanical engineering Indian institute of science of technology Guwahati. Indian Journal of Biotechnology 6:410-413.

Food Agriculture Organization (FAO) (2006). World reference base for soil resources 2006. A framework for international classification, correlation and communication. World Soil Resources Reports 67:70-88. 11. http://www.fao.org/3/a-a0510e.pdf

Food Agriculture Organization (FAO) (2014). The state of food and agriculture. http://www.fao.org (accessed Oct 10, 2017)

Jaetzold R, Schmidt H, Hornetz B, Shisanya C (1982). Farm Management Handbook of Kenya. Central Kenya (Rift Valley and Central Provinces), Kenya. https://www.uni-trier.de/index.php?id=58581

Jaetzold R, Schmidt H, Hornetz B, Shisanya C (2012). Farm management handbook of Kenya. http://www.fao.org (accessed Sep 20, 2017).

Janssens SR, Wiersema SG, Goos HT (2013). The value chain for seed and ware potatoes in Kenya: Opportunities for development (No. 13-080). LEI Wageningen UR.

Mainuri ZG, Owino JO (2013). Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro watershed in Kenya. International Soil and Water Conservation Research l1:80-87.

Munroe G (2007). Manual of on-farm vermicomposting and vermiculture. Organic Agriculture Centre of Canada.

Okello JJ, Yuan Z, Norman K, Sylvester O, Ian B, Elma SG, Elly A, Justin TA (2017). Productivity and food security effects using certified seed potato: the case of Kenya's potato farmers. Agriculture and Food Security 6:25.

Peter R, Wachira K, Oscar O, Agajie T, Gebremedhin W (2009). Improving potato production in Kenya, Uganda and Ethiopia: A system diagnosis. Potato Research 52:173-205.

Riungu C (2011). No easy walk for potatoes. E.A. Fresh Produce 19:16-17.

Rose C, Parker A, Jefferson B, Cartmell E (2015). The characterization of feces and urine: A review of the literature to inform advanced treatment technology. Critical Reviews in Environmental Science and Technology 45:1827-1879.

Scott GJ, Rosegrant MW, Ringler C (2000). Global projections for root and tuber crops to the year 2020. Food Policy. 25:561-597.

Sinha RK, Agarwal S, Chauhan K, Chandran V, Kiranbhai B (2010). Vermiculture Technology: Reviving the Dreams of Sir Charles Darwin for Scientific Use of Earthworms in Sustainable Development Programs. Scientific Research 1:155-172.

Souza PA, Souza G, Menezes JB, Bezerra NF (2008). Evaluations of cabbage cultivar grown under organic compost and mixed mineral fertilizers. Horticulture 26:143-145.

Usman M, Madu VU, Alkali G (2015). The Combined Use of Organic and Inorganic Fertilizers for Improving Maize Crop Productivity in Nigeria. International Journal of Scientific and Research Publications 5:10.

Vinnerås B, Palmquist H, Balmér P, Weglin J, Jensen A, Andersson Å, Jönsson H (2006). The characteristics of household wastewater and biodegradable waste – a proposal for new Swedish norms. Urban Water 3:3-11.

Were HK, Kabira JN, Kinyua ZM, Olubayo FM, Karinga JK, Aura J, Lees AK, Cowan GH, Torrance L (2013). Occurrence and Distribution of Potato Pests and Diseases in Kenya. Potato Research 56:325-342.

Vol. 13(36), pp. 1888-1900, 6 September, 2018
DOI: 10.5897/AJAR2018.13357
Article Number: DBA74FB58423
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Factors affecting the adoption of agricultural innovations on underutilized cereals: The case of finger millet among smallholder farmers in Kenya

Rebecca Jerop[1*], Peter Dannenberg[3], George Owuor[1], Patience Mshenga[1], Paul Kimurto[2] Maximilian Willkomm[3] and Gideon Hartmann[3]

[1]Department of Agricultural Economics and Agribusiness Management, Egerton University, P. O. Box 536-20115 Egerton, Kenya.
[2]Department of Crops, Horticulture and Crop Sciences, Egerton University, P. O. Box 536-20115 Egerton, Kenya.
[3]Institute of Geography, University of Cologne, Albertus-Magnus-Platz, 50923 Cologne, Germany.

Received 29 June, 2018; Accepted 27 July, 2018

Agricultural innovation adoption is fundamental in increasing incomes and food output in developing countries. However, the factors that influence farmers' decisions to adopt innovations in underutilized crops are not well-documented. Underutilized crops like finger millet have been an alternative form of sustenance for resource-poor farmers especially in arid and semi-arid areas in Kenya. They are more nutritive and resilient to environmental extremes and harsh weather conditions than common crops like maize. The study presented sought to investigate factors that facilitate or impede the probability and level of use of different innovations (improved varieties, conservation tillage, integrated pest and weed management, and group marketing) on the production and marketing of these crops. A multi-stage sampling technique was used to survey 384 finger millet producers in Elgeyo-Marakwet County, Kenya. The study employed a multivariate probit to model simultaneously the interdependent adoption decisions of finger millet farmers and an ordered probit to determine the level of adoption. The results reveal that plot size, off/non-farm income, household credit, and extension contact positively influence the decision to adopt and the level of adoption. Technical training positively affects the level of adoption but negatively influences the probability of adopting some innovations. Awareness of these factors could allow the development of strategies, policies, and plans to increase the uptake and sustenance of agricultural innovations on the production and marketing of finger millet and could, consequently, contribute to the food security and incomes of finger millet farmers through enhanced productivity and marketing of the crop.

Key words: Agricultural innovations, adoption, underutilized cereals, smallholders, Kenya.

INTRODUCTION

The adoption of agricultural innovations is crucial to increase incomes and food output in developing countries to meet the needs of the continuing growing population (Pingali, 2012).

*Corresponding author. E-mail: rebby.jerop@gmail.com.

Following the dawn of the green revolution, strenuous efforts to increase the adoption of agricultural innovations, such as improved varieties for wheat, rice, and maize, chemicals, machinery, and irrigation among producers resulted in a significant increment in incomes and global food output (Adhikari et al., 2018) especially in the global North as well as in emerging economies in Asia (Toenniessen, et al., 2008). However, in practice, the approach also brought environmental issues, health and social problems, monoculture, and the growth of unsustainable farming systems (Yapa, 1993; Dawson et al., 2016). The successes and limitations of this approach have been subject to debates for several years, calling for more sustainable methods to increase food output and incomes. In this context, diversification toward underutilized crops and the adoption of environmentally sustainable practices has gained more attention, especially in developing regions like Sub-Saharan Africa (Mabhaudhi et al., 2016).

A major part of agricultural innovation research focuses on widely consumed and traded cereal crops such as rice, wheat, and maize (Ejeta, 2010; Godfray et al., 2010; Pingali, 2012; Guti et al., 2018), while cereal crops important to African smallholders, commonly known as underutilized or orphan crops such as millet and sorghum, receive less attention (Tadele, 2014). Underutilized crops – like other crops – are classified into cereal crops such as millet and sorghum, legumes, root, and fruit crops (Tadele, 2009, 2014) and usually describe varieties that have long received little attention from farmers, consumers, scientists, and policy makers (Padulosi et al., 2013). Their cultivation used to be widespread in the past but was widely abandoned in favour of other – modern – crops today (Padulosi et al., 2002). Further, they are mostly not traded to a significant extent and, if so, only with a limited geographical reach (Naylor et al., 2004). In recent years, a strand of literature and strategies has emerged that promote particularly underutilized cereal crops including finger millet. It is argued that these could make an important contribution to food and nutritional security as well as to income generation to resource-poor farmers living in low productivity areas like the semi-arid climates of Sub-Saharan Africa for several reasons (Padulosi et al., 2013). These cereals are known to be more nutritious particularly in terms of increasing the supply of micronutrients (Tadele, 2014). Besides, they tend to be more resilient to poor or unpredictable agro-ecological conditions than commonly produced cereals such as maize, wheat, and rice (Tadele and Assefa, 2012). Despite their low adoption, underutilized crops therefore carry the potential to alleviate some of the most pressing issues in terms of food production in demanding agro-climatic conditions.

Nevertheless, underutilized crops are also attached to major bottlenecks: low yields and high labour requirements compared to other crops limit their productivity and marketing (Naylor et al., 2004). For instance, in Kenya huge gap exists between the yield of millet and major cereal crops like maize, wheat and rice (Table 1). Environmental factors, such as pest, diseases, and weeds, contribute to a large loss in yield and, consequently, limited or no marketable surplus (Pingali, 2012). The feasibility of growing underutilized crops is, therefore, strongly bound to how they are produced and marketed. Acknowledging the niche potential and the importance of innovative measures in production, there is a significant rise in promoting the introduction and adoption of innovations in these crops (Walker and Alwang, 2015). For instance, locally administered organizations such as the International Research Crops Institute for the Arid and Semi-Arid Tropics (ICRISAT) established programs that involve farmers to develop improved varieties and increase sustainable agricultural practices for traditional crops including millets (Goron and Raizada, 2015). The promotion and adoption of innovations on these crops therefore are witnessed in most parts of unfavourable environments of Sub-Saharan Africa (Pingali, 2017).

In Kenya, numerous donor-funded organizations are fostering the development, dissemination, and adoption of various innovations in finger millet and other underutilized crops with the aim of diversifying household nutrition and incomes especially in semi-arid areas. For instance, the International Research Crops Institute for the Arid and Semi-Arid Tropics (ICRISAT) and the Kenya Agricultural Livestock Research Organization (KALRO) in collaboration with Egerton University as well as seven selected counties in arid and semi-arid areas in Kenya are currently promoting innovations on finger millet and other underutilized crops. These research organizations released seed varieties which have been proven on field trials and on-stations to be more productive and resistant to striga weeds and blast diseases compared to the local varieties (Oduori, 2005; Mgonja et al., 2013). Farmers are also encouraged to employ low-cost and environmentally friendly practices, including integrated pest and weed management and conservation tillage to control finger millet diseases and weeds as well as conserving water and soil. This is because most finger millet farmers are resource-constraint and live in marginal areas (Mgonja et al., 2013). Further, since most finger millet farmers engage in subsistence production, these organizations are linking farmers to the market through the formation of finger millet collective marketing groups (aggregation centres) to promote economies of scale and sufficient market power amongst smallholders. The aim of these initiatives is to increase household nutrition through the diversification of diets and household incomes from marketable surplus in a sustainable manner for resilience and inclusive agricultural growth. This could be made possible through the adoption of these innovations by smallholder farmers.

In the agricultural sector, uniform adoption of agricultural innovations among smallholder farmers, however, is not common because of many factors (Awazi and Tchamba, 2018). Several studies (Langyintuo and Mekuria, 2005; Akudugu et al., 2012; Loevinsohn et al., 2013; Wairimu et al., 2016) agreed that the adoption of agricultural innovations depends on a range of farmer, farm, and institutional as well as innovational characteristics but studies addressing adoption problems affecting underutilized cereals are still scarce. A better understanding of the factors that affect farmers' adoption decisions on underutilized cereals like finger millet is necessary to design promising strategies to stimulate the adoption of these innovations.

Agricultural innovation adoption among smallholder farmers has received significant attention in the last decades. The terms "technology" and "innovation" are often used interchangeably in various strands of literature. For this article, however, the two are different. We agree with Rogers (2004) in defining innovation as an idea, practice, or knowledge that is new to a decision maker or the user, irrespective of whether it is new to other individuals or the country or the world. Agricultural innovation is a broad term which encompasses technical elements, such as improved varieties and sustainable agricultural practices, as well as organizational elements, such as collective action or farmer organizations, or institutional innovations which may be new operational instruments in the form of social norms, or operating procedures which facilitate effectiveness in processes (Triomphe et al., 2013; Makini et al., 2016).

Several studies (Olwande et al., 2009; Ogada et al., 2010; Mignouna et al., 2011; Ogada et al., 2014;) addressing factors that influence farmers' decisions to adopt or use new innovations are skewed toward widely consumed cereal crops especially maize. In contrast, little information exists on the factors influencing farmers' adoption decisions on various underutilized crops like finger millet innovations. The few existing studies have mainly focused on the adoption of technical innovations including hybrid varieties and the use of chemical fertilizer in finger millet production (Gitu, et al., 2014; Handschuch and Wollni, 2016). Most promoted innovations among smallholder finger millet farmers, however, are market-related and resource-conserving innovations aimed at increasing productivity in a sustainable manner as well as improving access to markets. There is no empirical evidence on the adoption of organizational innovations, such as group marketing and sustainable practices including conservation tillage and integrated pest and weed management, on finger millet. This study, therefore, aims at investigating factors that influence the farmers' decisions to use these innovations and the level of use. The objective is to fill this knowledge gap and to generate information to be used by researchers, extension officers, and development organizations in the finger millet production and marketing as well as other cases of underutilized crop production. Most of the market-related innovations combine aspects of technical innovation with organizational or institutional ones (Triomphe et al., 2013). The current study, thus, combines technical innovations such as improved finger millet varieties, conservation tillage, and integrated pest and weed management with organizational innovations like group marketing. Well, it can be generally discussed in how far fostering these innovations on underutilized crops might lead to unintended negative effects this paper focuses mainly on the factors which affect adoption of these innovations.

THEORETICAL FRAMEWORK

Smallholder households in Kenya and other developing countries produce and market agricultural products under uncertainty and imperfect market structures. Hence, finger millet farmers would invest in a given innovation if the expected utility of adoption U_k is higher than expected utility U_o without adoption (Borges et al., 2015). That is when $U_k > U_o$. Although the utility of farmers is not directly observed, the relationship between the expected utility and innovation adoption is postulated to be a function of the characteristics observed and a random disturbance term that arises from unobserved factors. The strand of literature on adoption group these observed factors into various categories: farmer characteristics, farm-specific factors, and institutional and innovational factors (Langyintuo and Mekuria, 2005; Saka and Lawal, 2009; Chuchird et al., 2017).

However, increasing finger millet productivity demands the multiple adoption of these agricultural innovations including improved varieties of finger millet, conservation tillage, integrated pest and weed management, and group marketing to achieve higher yields and promote the sustainability of the smallholder farming systems as well as transform subsistence farming to market-oriented agriculture. This implies that the adoption decisions of finger millet farmers are basically multidimensional. In this case, there is a high chance that the adoption of one finger millet innovation can alter the likelihood of adopting another, resulting in potential interdependence between unobserved factors as well as the adoption of different practices. The source of interdependence could be complementarity (positive) and substitutability (negative) (Wainaina et al., 2016). This study, therefore, hypothesized that the adoption decisions of finger millet farmers on improved finger millet varieties (IV), conservation tillage (CT), integrated pest and weed management (IPW), and group marketing (GM) are interdependent. The decision also depends on the expected utility of the innovation measured by observed factors such as farmer (age, education, household size, and gender), farm (plot size and off/non-farm income), and institutional factors (access to information, access to credit, and access to infrastructure such road or market) (Loevinsohn et al., 2013).

EMPIRICAL ESTIMATION

Multivariate probit

A multivariate probit model (MVP) and an ordered probit model were used to determine the probability and the level of adoption of agricultural innovations by finger millet farmers. The MVP simultaneously models the influence of explanatory factors on each of the four innovations, allowing potential correlations of unobserved factors among the adoption decisions. Correlation may result from innovational complementarity or substitutability. MVP is a model which has been used by several studies to assess adoption decisions of multiple technologies (Teklewold et al., 2013; Wainaina, et al., 2016). It is an extension of the probit model (Greene and Hensher, 2010) and is used to analyse several correlated binary outcomes jointly (Temesgen et al., 2017). The model is specified as follows;

$$Y_{ij}^{*} = x_{ij}\,\beta_j + u_{ij}, \quad \text{j=1………4} \tag{1}$$

Where *j*=1…., 4 denotes the innovational binary choices available, namely: improved varieties, conservation tillage, integrated pest and weed management, and group marketing.

In Equation 1, the assumption is that a rational i^{th} farmer $i = 1, \ldots., n$ has a latent variable, Y_{ij}^{*}, which captures the unobserved preferences or demand associated with the j^{th} choice of agricultural innovations. This latent variable is assumed to be a linear combination of observed characteristics x_{ij} that is the farmer, farm and institutional characteristics affecting the adoption of j^{th} innovation, as well as unobserved characteristics captured by the stochastic error term u_{ij}. The vector of parameters to be estimated is denoted by β_j. Given the latent nature of Y_{ij}^{*}, the estimations are based on observable binary discrete variables Y_{ij}, which indicate whether a farmer adopts an innovation or not.

Using the indicator function, the unobserved preferences in Equation 1 translate into the observed binary outcome equation for each choice as follows:

$$Y_{ij} = \begin{bmatrix} 1 \; if \; Y_{ij}^{*} > 0 \\ o \; otherwise \end{bmatrix} \tag{2}$$

Since adoption of several innovations is possible, error terms in Equation 1 jointly follow a multivariate normal distribution, with zero conditional mean and variance normalized to unity, where u_{ij} ~MVN (0, Σ) and the covariance matrix Σ is given by:

$$\begin{pmatrix} u_{1i} \\ u_{2i} \\ u_{3i} \\ u_{4i} \end{pmatrix} \sim \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{21} & 1 & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & 1 & \rho_{34} \\ \rho_{41} & \rho_{42} & \rho_{43} & 1 \end{bmatrix} \tag{3}$$

This assumption means that Equation 3 gives an MVP model that jointly represents decisions to adopt an innovation. This specification with non-zero off-diagonal elements allows for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative agricultural innovations. Numerous studies (Wainaina et al., 2016; Temesgen et al., 2017) have employed Geweke–Hajivassiliou–Keane (GHK) to compute the maximum likelihood function based on multivariate normal probability distribution. The GHK simulator is primarily based on multivariate normal distribution function that can be expressed as the product of sequentially conditioned univariate normal distribution functions, which can be accurately evaluated (Cappellari and Jenkins, 2003). The current study therefore, used the GHK simulator to estimate the equations using maximum likelihood method.

Ordered probit model

The level of use of agricultural innovations in production and marketing of finger millet was estimated using ordered probit model. Finger millet farmers may adopt one or multiple innovations to increase productivity and marketing. Multivariate probit only predicts the factors that influence the adoption decision, hence not distinguishing between those farmers who used one innovation and those who used multiple innovations in different combinations. Consequently, it is difficult to determine the cut-off points between users and non-users of agricultural innovations and the associated factors (Maguza-Tembo et al., 2017). Therefore, an additional model (ordered probit model) to assess the level of adoption and the factors influencing innovations was employed. Following Teklewold et al. (2013), the dependent variable for the level of adoption is based on the number of innovations adopted. This measure is ordinal and as a result ordered probit and poison regression model can be employed (Maguza-Tembo et al., 2017). However, the biggest shortcoming of poison regression model assumes all the innovations to have equal chances of being adopted (Boz, 2014). In the current study, the probability of adopting the first innovation could differ from the probability of adopting the second or third, given that adopting the second or more innovations may depend on the probability of adopting the first innovation. The number of innovations used by finger millet farmers is an ordinal variable and, thus, we use an ordered probit model in the estimation.

The adoption decision is based on an expected utility framework. The farmer decides to adopt additional innovation if the utility derived from adopting it is higher than not adopting it. Since the utility level of a farmer is not observed (Y_i^*), the observed level of adopted innovations (Y_i) is related to the latent variable (Y_i^*), as presented in the following equations:

$$Y_i^* = X_i\beta + u_i \quad (i = 1,2 \dots .n) \tag{4}$$

$$Y_1 = 0 \;\; if \; Y_i^* < \delta_1 \tag{5}$$

$$Y_2 = 1 \;\; if \, \delta_1 \leq \; Y_i^* < \delta_2 \tag{6}$$

$$Y_3 = 2 \;\; if \, \delta_2 \leq \; Y_i^* < \delta_3 \tag{7}$$

$$Y_4 = 3 \;\; if \, \delta_3 \leq \; Y_i^* < \delta_4 \tag{8}$$

$$Y_5 = 4 \;\; if \, \delta_4 \leq \; Y_i^* \tag{9}$$

where u_i are the residual error terms and $\delta_1 < \delta_2 < \delta_3 < \delta_4$ are threshold parameters that are empirically estimated using β.

METHODOLOGY

Study area, sampling, and data collection

The study was carried out in Elgeyo-Marakwet County in December 2016. The case study site was chosen due to the various initiatives in the area targeting the improvement of livelihoods using traditional, underutilized crops and owing to its socio-economic conditions since 57% of people live below the poverty line (CIDP,2013-2017). In Elgeyo-Marakwet, finger millet together with sorghum used to be the most important cereal crops until the introduction of maize (Östberg, 2015). The production and consumption of these crops declined due to the shift toward maize production among smallholder farmers and recent widespread neglect by researchers and policy makers. For this work, we draw from a survey with 384 finger millet smallholder farmers based on multi-stage sampling. The first stage involved purposive selection of the county. Purposive selection further served to select two sub-counties and two wards from each sub-county to be included in the analysis owing to the intensity of finger millet production. Finally, smallholder finger millet farmers were randomly sampled from the four wards. The determination of the sample size followed proportionate to size sampling methodology as specified by Anderson et al. (2016). Sets of structured and semi-structured questionnaires, organized into five sections were used to collect data. The first section was dedicated to obtaining information on the socio-economic and demographic characteristics of the survey respondent like age, education, gender, and the number of members in the household as well as household assets. The second and third sections were devoted to understanding the farm attributes and the production and marketing of crops by the farmer. The fourth section was mainly to obtain information on the institutional and organizational characteristics of the farmer, followed by the last section committed to identifying various innovations used by finger millet farmers. Data were analysed using STATA version 14.2 software. Both descriptive and inferential statistics describe the statistical apparatus to analyse the data.

RESULTS AND DISCUSSION

Descriptive statistics

Finger millet improved varieties

The results of the current study indicated that about 40% of the sampled finger millet farmers in the 2015/2016 cropping season used improved finger millet varieties. The sources of finger millet seeds were their own recycled seeds from previous growing seasons (stock), local markets, the government extension program, research organizations (ICRISAT, KALRO and Egerton University), and private seed suppliers. From these sources, own recycled seeds from previous growing seasons and local markets shared the greater amount of finger millet seeds planted by the sample farmers.

Conservation tillage

Conservation tillage was one of the important innovations used by finger millet farmers (52%) to enhance the productivity and conservation of the resource. Most of the finger millet smallholders attested that they leave most of the soil surface covered with crop residue at planting time; some of the smallholder finger millet farmers also till planting rows and later carry out mechanical weeding or hand-pull weeds. The users of conservation tillage obtained the idea from Egerton University, ICRISAT, and other research institutions, 35% got the information from government extension officers and approximately 10% of the farmers learned from other fellow farmers.

Integrated pest and weed management practices (IPMW)

Results indicated that about 64% of the sampled farmers used integrated pest and weed management practices (IPMW) to control pests in the 2015/2016 cropping season. In this regard, IPMW methods included the hand-pulling of weeds and burning before flowering (51%), the

Table 1. Yield of selected cereals crops in Kenya (2016).

Crop	Yield in ton/ha
Maize	1.42
Wheat	1.45
Rice	4.03
Millet	0.61
Sorghum	0.63

Source: FAOSTAT statistical division.

use of traps and baits (42%), early planting (15%), the use of other plants (cow pea, pigeon pea and groundnuts) to trap and destroy pests and diseases and control some weeds (27%), and crop rotation (31%). Most of these practices were used in combinations of two or a maximum of three.

Group marketing

The study found out that only 28% of finger millet farmers had embraced group marketing as a means for accessing a market for their produce. Members of the group aggregate their output and look for one buyer to increase their economies of scale and bargaining power. Most of the farmers interviewed indicated they received advice on a new way of marketing finger millet output from Egerton University and county government extension officers.

Description of farmer, farm and institutional characteristics

As shown in Table 1, out of the 384 households interviewed, about 87% were headed by males, while the remaining 13% were headed by females. The proportion of household heads in the sample is much lower compared to the national level (that is, one third of the total rural household heads is female). The average age of the sample household head was found to be 42 years. On average, a household head had approximately 8 years of formal education. The average area cultivated for finger millet production during the 2015/2016 cropping season was 0.6 acres, which accounts for about 30% of the average total cultivated land size and 40% under cereal crops, respectively. The dominant cereal crop in the study areas is maize. It covers 36% of the average total crop area and 50% of the area under cereal crops, respectively. The results of the current study indicated that about 38% of the farmers interacted with extension officers approximately twice during the cropping period. As displayed in Table 1 about 28% of finger millet farmers had received technical training on finger millet from the research and learning institution on the technical aspects of various innovations. During the reference cropping season, only 13.8% of the sample farmers had received a cash credit for finger millet production from credit institutions. The walking distance measured in minutes from the farmers' residence to the nearby market was found to be about 50 minutes on average.

Adoption decisions and level of adoption

Multivariate probit results

Tables 2 and 3 present the maximum likelihood estimation results of our multivariate probit model on the factors influencing the decision of smallholder farmers to use innovations in finger millet production and marketing. The likelihood ratio test (X^2(6) =19, Prob<0.000) of the independence of the residual terms is strongly rejected at a one percent level of significance, implying that the multiple use of innovations is not mutually independent. They are interdependent and, consequently, support the use of MVP modelling. Table 3 shows the correlation between the error terms of the innovations. The correlation coefficients were statistically different from zero in three of the six pair cases and all the three cases were positive, indicating complementarity among the innovations studied.

Gender of the household head

Keeping other variables in the model constant, the gender of the household head had a negative and significant influence on the likelihood of using conservation tillage at a 1% level of significance. The negative effect implied that female-headed households were more likely to adopt conservation tillage compared to their male counterparts. This is of interest because in most African countries, men leave many of the finger millet management practices to women including land preparation, seeding/transplanting, harvesting, and threshing (Thilakarathna and Raizada, 2015). Hence, females are more likely to adopt conservation tillage because it is frequently cited as having labor-saving properties.

Table 2. Agricultural innovations and explanatory variables.

Variables	Description	Mean	Std
Innovations(Dependent variables)			
Improved variety *(IV)*	use of the innovation 1=yes and 0 otherwise	0.409	0.492
Conservation tillage *(CT)*	use of the innovation 1=yes and 0 otherwise	0.518	0.5
Integrated pest management *(IPW)*	use of the innovation 1=yes and 0 otherwise	0.638	0.481
Group marketing *(GM)*	use of the innovation 1=yes and 0 otherwise	0.281	0.45
Explanatory variables			
Gender	1=if sex of the head is male	0.865	0.343
Education	Years of schooling of household head	8.81	3.851
Age	Age of the household head in years	42.383	12.168
Household size	Family size number of household members living together for the past six months	5.297	2.108
Plot size	Size of the plot allocated to finger millet in acres	0.601	0.44
Off/non-farm income	Kenya Shillings	37324.48	88389.8
Household credit	Received credit for the crop 1=Yes and 0=No	0.138	0.345
Extension	Received extension services 1=Yes and 0=No	0.300	0.458
Extension contact	Number of contacts with extension officer per year	1.770	1.126
Technical training	Received technical training 1=Yes and 0=No	0.276	0.448
Distance to the nearest market	Distance to the nearest market in walking minutes	50.208	48.221

Source: Survey data (2016).

Table 3. Estimated covariance matrix of the regression equations between innovations using multivariate probit model.

	ρ^{IV}	ρ^{IPW}	ρ^{CT}	ρ^{GM}
ρ^{IV}	1			
ρ^{IPW}	0. 188 (0. 092)**	1		
ρ^{CT}	-0. 023 (0.089)	0. 227 (0. 087)***	1	
ρ^{GM}	0. 059 (0. 095)	0. 162 (0. 093)	0. 250 (0. 086)***	1

Likelihood ratio test of P (IPW) (IV)= P (CT) (IV) = P (GM) (IV) = P(CT) (IPW) = P (GM) (IPW = P (GM) (CT = 0: X^2(6) = 19.704
Prob > X^2 = 0.0031.
*, **, and *** indicate statistical significance at 10, 5, and 1% level of significance.
Source: Survey data (2016).

The findings concur with those of other studies (Chalermphol et al., 2015; Asfaw and Neka, 2017; Wossen et al., 2017).

Age of the household head

Young household heads had a higher tendency toward adopting integrated pest and weed management at a 10% level of significance. This implies that younger finger millet farmers were 46% likely to adopt integrated pest and weed management than older farmers. Younger farmers are often better educated and tend to be more aware of the benefits of new innovations. This relationship between age and innovativeness is similarly observed by Ghimire and Kafle (2014) who also reported a negative relationship between age and the use of integrated pest management.

Education of the household head

Consistent with the work of Bruce (2015) on innovation adoption, the education of the household head had a positive and significant impact on the adoption of conservation tillage and integrated pest and weed management at a ten and 5% level of significance, respectively. Educated farmers are believed to have a higher ability to obtain, interpret, and respond to new information about technologies than their peers with little or no education (Namara et al., 2014). More educated farmers are, furthermore, more likely to access information and advice from extension workers which influence their adoption and use of these innovations.

Size of the farming household

The size of the farming household had a positive and significant influence on adoption of finger millet improved varieties, which was statistically significant at 1% level. That is, an increase in the size of the household increased the probability of adopting improved varieties of finger millet by 10.2% when other factors are held constant. This could be explained by the fact that an increase in the size of the household implies an increased demand for food. To meet the demand, the household seeks better finger millet varieties that will increase the output. The results also reveal that the size of the farming households negatively influenced the adoption of conservation tillage and group marketing which were statistically significant at five and 10%, respectively. That is, holding all factors constant, an increase in the size of the household decreased the use of conservation tillage and group marketing by 9.7 and 7.3%, respectively. These findings suggest that small households are more likely to adopt conservation tillage and group marketing as compared to larger households. Conservation tillage is labour- and resource-saving technology that small households with less family labour could be more inclined to adopt unlike larger households (Rockström et al., 2009). Large households are less likely to join group marketing because there is high demand for food and may have no or less surplus for the market, since most farmers in the study area attested that they produced finger millet mainly for subsistence.

Land size allocated to finger millet

The results also show that the plot size positively influenced finger millet farmers to join group marketing at 1% level. That is, an increase in plot size under finger millet would increase the probability of adopting group marketing at 82%, other factors held constant. This can be explained by the fact that large area of agricultural land provides opportunity for surplus production hence, farmers joined group marketing to linked them to markets to absorb their surplus production at lower marketing cost.

Off-/non-farm income

The findings further reveal that the presence of off-farm income positively influenced the adoption of integrated pest management which was statistically significant ($p<0.01$). That is holding other factors constant, a unit increase in off-farm income would increase the likelihood of adopting integrated pest and weed management at 9%. This is consistent with the findings of Muriithi et al. (2016) where extra income earned from non-agro-based activities positively influenced the adoption of integrated pest management technology. However, the results contradict the findings by Asfaw and Neka (2017) where off-farm income had a negative effect on the adoption of soil and water conservation technologies

Extension services

The findings also show that access to extension services positively and significantly influences the adoption of all the four innovations, namely, improved variety, conservation tillage, integrated pest and weed management, and group marketing. The results support the apparent tendency that farmers accessing extension services increases their likelihood of adopting various technologies. Farmers have a higher likelihood of changing their farming and marketing styles if they are more informed, as is the case with extension services that disseminate agricultural information. Therefore, the more access to information farmers have, the more likely they are to adopt and embrace innovations in the production and marketing of finger millet. The findings are consistent with Muriithi et al. (2016)'s results, where access to extension services had a positive impact on the adoption of integrated pest management practices in the suppression of mango-infesting fruit flies.

Technical training

The technical training of farmers on the usage of innovations in finger millet had a positive impact on integrated pest and weed management. This implies that farmers who had technical training had a higher chance of adopting the IPWM innovations for farming finger millet as opposed to their counterparts who had no training. This is anticipated since training impacts knowledge and gives an opportunity for farmers to learn how to best use innovations. The results are similar with (Pierpaoli et al., 2013) findings. The results of the current study also concur with those of Jayasooriya and Aheeyar (2016) where the knowledge of farmers of integrated pest management had a great influence on the use of the practices, indicating the possibility of increasing adoption through awareness and training. However, technical training had a negative and significant impact on improved seed varieties at a 10% level of significance. The findings though not expected were consistent with the findings of Murage et al. (2015) where the type of information accessed during training had a negative impact on the adoption of innovations. Technical training

Table 4. Multivariate probit model results on factors influencing adoption decision.

Variables	Improved variety		Conservation tillage		IPWM		Group marketing	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Gender	-0.020	0.214	-0.598***	0.209	0.238	0.210	-0 .174	0.216
Education	0.014	0.021	0.039*	0.021	0.043**	0.022	0. 023	0.021
Age	-0.009	0.005	0.002	0.006	-0.012*	0.007	0.023	0.006
Household size	0.100***	0.037	-0.097**	0.038	-0.257	0.038	-0.073*	0.039
Plot size	0.277	0.175	0.086	0.163	0.257	0.166	0.825***	0.175
Off/Non-farm income	0.020	0.014	0.009	0.014	0.090***	0.015	0.008	0.014
Household credit	0.881***	0.213	0.427**	0.215	0.332	0.228	-0.136	0.209
Extension contact	0.451***	0.091	0.600***	0.096	0.167*	0.088	0.204***	0.076
Technical training	-0.441***	0.192	0.237	0.175	0.92***	0.218	0.124	0.173
Distance to market	-0.001	0.002	-0.001	0.002	-0.001	0.002	0.004**	0.002
Constant	-0.870***	0.326	0.359	0.307	0.428	0.322	-0.916***	0.320
Number of observations		384						
Log likelihood		-816.375						
Wald chi2(44)		263.64***						

*, **, and *** indicate statistical significance at 10, 5, and 1 percent level of significance.
Source: Survey data (2016)

on an innovation may result in shifting resources in its favour, leading to high adoption and consequently less attention may be given to other innovations.

Access to credit

The findings show that access to credit positively and significantly influences the use of improved variety and conservation tillage at a 1% level of significance. That is, farmers who access credit have a higher likelihood of adopting the technologies than those who do not access credit. Most technologies require financing with a significant amount of money. If the farmers cannot self-finance their farming, access to credit fills the gap to enabled increased production. That is, farmers who have more access to money can purchase improved seeds for finger millet and they can also pay for the time taken to practice row planting as opposed to broadcasting and other conservation tillage practices. Thus, access to credit increases the chances of farmers adopting technological innovations in the production and marketing of finger millet. The current findings concur with past findings of (Wossen et al., 2017).

Distance to the market

The walking distance to the market also significantly and positively influences the adoption of group marketing at 1%. That is, for a unit increase in distance to the market, the chances of a farmer adopting group marketing increases by 0.37%. Distance to the market is a proxy for infrastructure and time spent by farmers traveling which results in higher marketing costs. Therefore, the greater the distance, the more willing the farmers are to reduce costs and join a marketing group to share transport and other marketing costs. Mottaleb et al. (2016) also found that the distance positively influenced the adoption of agricultural technology.

Ordered probit results

The chi-square statistics of the ordered probit is 154.42 and is statistically significant at a 1% level of significance. For the interpretation of the ordered probit, the study used marginal effects after estimation of the ordered probit model. Marginal effects are presented in Table 4. The results reveal that if any household were taken at random, there would be an 8% likelihood that they had adopted none of the innovations with a 92% likelihood of adopting at least one innovation in finger millet production. Among the eleven explanatory variables entered into the model, only five were statistically significant at a 1% level. The significant variables were plot size, off/non-farm income, extension contact, household credit, and technical training.

Holding all other factors constant, an increase in the area allocated to finger millet production increases the probability of adopting two, three, or four innovations by 31, 10.5 and 5.8%, respectively, and reduces the

Table 5. Ordered probit results with marginal effects on factors influencing the level of adoption.

Variables	Ordered probit		Marginal effects				
	Coeff.	SE	Prob(Y=0|X)	Prob(Y=1|X)	Prob(Y=2|X)	Prob(Y=3|X)	Prob(Y=4|X)
			dy/dx	dy/dx	dy/dx	dy/dx	dy/dx
Gender	-0.204	0.163	0.029	0.045	-0. 007	-0.041	-0.026
Education	0.011	0.015	-0.002	-0.003	0.001	0.002	0.001
Plot size	0.517***	0.129	-0.082***	-0.113***	0.031**	0.105***	0.058***
Age	0.001	0.186	0.004	0.005	-0.001	-0.005	-0.003
Household size	-0.035	0.028	0.006	0.008	-0.002	-0.007	-0.004
Off farm income	0.044***	0.106	-0.007	-0.009	0.002**	0.009***	0.004***
Household credit	0.605***	0.162	-0.072***	-0.134***	-0.009	0.119***	0.095***
Extension contacts	0.468***	0.064	-0.075***	-0.102***	0.028***	0.095***	0.053***
Technical training	0.315***	0.135	-0.046***	-0.069***	0.011	0.065***	0.040***
Distance to the Market	0.001	0.001	0.002	-0.001	0.000	0.000	0.001
δ_1	-0.545	0. 231					
δ_2	0.420	0. 228					
δ_3	1.422	0. 234					
δ_4	2.335	0. 250					
Observation	384						
Wald chi2(10)	154.42						
Prob>chi2	0						
Log Likelihood	-512.143						
Pseudo R2	0.13						

*, ** and *** indicate statistical significance at 10,5 and 1 percent level of significance.
Source: Survey data (2016).

probability of adopting one or none by 11.3 and 8%, respectively. Increasing the amount of land allocated to finger millet production can reveal the farmer's preference for the crop and, consequently, the adoption of more innovations to maximize output returns. For finger millet farmers employing off-farm activities, the probability of adopting two and more innovations, thus, increases. These results are reasonable since farmers who have diversified their income-generating activities are generally more capable of facilitating the adoption of more innovations than their counterparts.

Given the nature of the agricultural innovation, contact with extension services is critical for the diffusion of information on innovations. For every additional contact of finger millet farmers with extension officers, the probability of using more than two innovations increases by 2.8%. These findings are consistent with Teklewold et al. (2013) where access to extension services affected the number of technologies adopted by farmers. Similarly, access to credit increases the likelihood of adopting three or more finger millet innovations. This can be explained by the fact that credit is an incentive to increase the production of finger millet and enables investment in inputs. Moreover, access to credit implies the ability of the farmer to finance the adoption of any innovation that would require an extra investment (Table 5). Technical training on innovations had a positive effect on the number of innovations adopted. Households that received some technical training on innovations were more likely to adopt more than three innovations than those that did not. This is anticipated to be the case since farmers are interested in adopting innovations that they possess a working knowledge. That is, if farmers know how a certain innovation works, the more they are likely to make use of it.

CONCLUSION AND RECOMMENDATIONS

This paper investigated the factors that influence finger millet adoption and level of adoption of different agricultural innovations in Elgeyo-Marakwet County. Innovations considered in the study included: improved seed varieties, conservation tillage, and integrated pest and weed management as well as group marketing. Some of the innovations exhibit complementarity, indicating interdependence. Household and farm characteristics as well as institutional conditions were the factors examined as to whether they influence the use of these innovations.

The results revealed that households with young household heads were more likely to adopt integrated pest and weed management. Moreover, the education of the household head had a positive and significant impact on the adoption of conservation tillage. The findings further highlight the high importance of extension services: consulting with extension officers positively and significantly influences the adoption of all the innovations considered in the study. Access to credit positively and significantly influences the use of improved seed varieties and conservation tillage. Although, the technical training of farmers on the adoption of innovations in the production of finger millet had a positive impact on integrated pest and weed management, it had negative effects on the adoption of improved seed varieties. The ordered probit results confirmed that the level of adoption of agricultural innovations was strongly related to farm and institutional factors. Those households who had allocated more land to finger millet, farmers with extra income from non-farm activities and who had better access to credit and extension services were likely to use more than two innovations.

Based on the findings, strategies aiming to promote innovation adoption for finger millet could place more emphasis on strengthening the existing agricultural extension service provision to improve the uptake of these innovations. Relevant stakeholders could invest in extension services to sensitize finger millet farmers to new innovations, as these have the potential to increase the adoption rate and, consequently, might increase farmers' productivity and incomes. Moreover, farmers could be trained on the technical aspect of these innovations as well as their associated benefits. Strides also need to be made in improving smallholders' financial capability to access credit and empowering farmers' institutions that can provide credit services at an affordable cost. While this study presents evidence on factors that influence the uptake of innovations in production and marketing of finger millet, it is confined to information provided by finger millet farmers at household level. We suggest that future studies could also obtain data from other key players within the production and marketing of these underutilized cereal crops (e.g. extension staff). This will help to better understand issues such as the kind of policies and market environments that can facilitate farmers' adoption decisions.

Further, this study used cross-sectional data collected from randomly sampled farmers to provide representative information needed in the development of underutilized cereal crops. Our study identified key farmer, farm and institutional characteristics that could be targeted for improvement to accelerate the adoption rate of these innovations. However, our data did not permit analysis of the dynamics of innovation adoption decisions. We recommend that future studies could employ panel data to capture dynamic elements that influence adoption choices amongst underutilized cereal farmers.

Lastly, this study explicitly focusses on the factors of adoption without addressing the implications of such adoptions. Although mainly for more common crops, the discussion and debate about the different innovation types has taken place in other parts of academic literature and we welcome further research on the impacts of different innovations particularly for underutilized cereal crops.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The study is an extract from the first author PhD thesis funded by the German Academic Exchange Service (DAAD) through the African Economic Research Consortium (AERC). The enumerators are gratefully acknowledged for collecting the data and the survey respondents for answering our questions. The views expressed in this study are solely those of the authors and not those of the affiliated institutions.

REFERENCES

Adhikari P, Araya H, Aruna G, Balamatti A, Banerjee S, Baskaran P, Dhar S (2018). System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: Experience with diverse crops in varying agroecologies. International Journal of Agricultural Sustainability 16(1):1-28.

Akudugu M, Guo E, Dadzie S (2012). Adoption of modern agricultural production technologies by farm households in Ghana: What factors influence their decisions. Journal of Biology, Agriculture and Healthcare 2(3)

Anderson D, Sweeney D, Williams T, Camm J, Cochran J (2016). Statistics for business and economics: Nelson Education.

Asfaw D, Neka M (2017). Factors affecting adoption of soil and water conservation practices: The case of Wereillu Woreda (District), South Wollo Zone, Amhara Region, Ethiopia. International Soil and Water Conservation Research 5(4):273-279.

Awazi N, Tchamba M (2018). Determinants of small-scale farmers adaptation decision to climate variability and change in the North-West region of Cameroon. African Journal of Agricultural Research 13(12):534-543.

Borges JAR, Foletto L, Xavier VT (2015). An interdisciplinary framework to study farmers decisions on adoption of innovation: Insights from Expected Utility Theory and Theory of Planned Behavior. African Journal of Agricultural Research 10(29):2814-2825.

Boz İ (2014). Determination of best management practices and innovations in beef cattle farming and their adoption in the eastern mediterranean region of turkey. Bulgarian Journal of Agricultural Science 20(3): 552-562.

Bruce AKK (2015). Improved Rice Variety Adoption and Its Effects on Farmers' output In Ghana. (Doctoral dissertation)

Chalermphol J, Bastakoti GB, Bastakoti RC (2014). Adoption of Improved Varieties of Vegetable Crops with Pesticide Use in Chiang Mai Province, Northern Thailand. Procedia Environmental Sciences 20:418-424.

Cappellari L, Jenkins SP (2003). Multivariate probit regression using simulated maximum likelihood. Stata Journal 3(3):278-294.

County Development Plan (CIDP) (2013). Elgeyo-Marakwet County Integrated Development Plan. Elgeyo Marakwet Kenya.

Chuchird R, Sasaki N, Abe I (2017). Influencing Factors of the Adoption of Agricultural Irrigation Technologies and the Economic Returns:

A Case Study in Chaiyaphum Province, Thailand. Sustainability 9:1524
Dawson N, Martin A, Sikor T (2016). Green revolution in Sub-Saharan Africa: implications of imposed innovation for the wellbeing of rural smallholders. World Development 78:204-218
Ejeta G (2010). African Green Revolution needn't be a mirage. Science 327(5967):831-832.
Gitu W, Onyango A, Obara A (2014). Selected Factors Affecting Adoption of Improved Finger Millet Varieties by Small-Scale Farmers in the Semi-Arid Mogotio District, Kenya. International Journal of Sciences, Basic and Applied Research 13:134-135.
Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Toulmin C (2010). Food security: the challenge of feeding 9 billion people. Science 327(5967):812-818.
Goron TL, Raizada MN (2015). Genetic diversity and genomic resources available for the small millet crops to accelerate a New Green Revolution. Frontiers in Plant Science 6:157.
Greene WH, Hensher DA (2010). Modeling ordered choices: A primer: Cambridge University Press.
Guti M, Palacios T, Ruiz-Vanoye A, Erez S, Opez. (2018). Sustainable and technological strategies for basic cereal crops in the face of climate change: A literature review. African Journal of Agricultural Research 13(5):220-227.
Handschuch C, Wollni M (2016). Improved production systems for traditional food crops: the case of finger millet in western Kenya. Food Security 8(4):783-797.
Jayasooriya H, Aheeyar MM (2016). Adoption and factors affecting on adoption of integrated pest management among vegetable farmers in Sri Lanka. Procedia Food Science 6:208-212.
Langyintuo AS, Mekuria, M (2005). Accounting for neighborhood influence in estimating factors determining the adoption of improved agricultural technologies. Paper presented at the American Agricultural Economics Association annual meeting, providence, Rode Island.
Loevinsohn M, Sumberg J, Diagne A, Whitfield S (2013). Under what circumstances and conditions does adoption of technology result in increased agricultural productivity? A Systematic Review. https://opendocs.ids.ac.uk/opendocs/handle/123456789/3208
Mabhaudhi T, Chibarabada T, Modi A (2016). Water-food-nutrition-health nexus: Linking water to improving food, nutrition and health in Sub-Saharan Africa. International Journal of Environmental Research and Public Health 13(1):107.
Maguza-Tembo F, Mangison J, Edris AK, Kenamu E (2017). Determinants of adoption of multiple climate change adaptation strategies in Southern Malawi: An ordered probit analysis. Journal of Development and Agricultural Economics 9(1):1-7.
Makini F, Kamau G, Makelo M, Mose L, Salasya B, Mulinge W, Ong'ala J (2016). Status of Agricultural Innovations, Innovation Platforms, and Innovations Investment. 2015 PARI project country report: Republic of Kenya.
Mgonja M, Audi P, Mgonja A, Manyasa E, Ojulong O (2013). Integrated Blast and Weed Management and Microdosing in Finger Millet: A HOPE Project Manual for Increasing Finger Millet Productivity. http://oar.icrisat.org/7607/1/A-HOPE-Project.pdf
Mignouna D, Manyong V, Rusike J, Mutabazi K, Senkondo E (2011). Determinants of adopting imazapyr-resistant maize technologies and its impact on household income in Western Kenya. AgBioForum 14(3):158-163. http://www.agbioforum.org.
Mottaleb KA, Krupnik, TJ, Erenstein O (2016). Factors associated with small-scale agricultural machinery adoption in Bangladesh: Census findings. Journal of rural studies 46:155-168.
Murage AW, Pittchar J, Midega C, Onyango C, Khan Z (2015). Gender specific perceptions and adoption of the climate-smart push–pull technology in eastern Africa. Crop Protection 76:83-91.
Muriithi BW, Affognon HD, Diiro GM, Kingori SW, Tanga, CM, Nderitu PW, Ekesi S (2016). Impact assessment of Integrated Pest Management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya. Crop Protection 81:20-29.
Namara RE, Hope L, Sarpong EO, De Fraiture C, Owusu D (2014). Adoption patterns and constraints pertaining to small-scale water lifting technologies in Ghana. Agricultural Water Management 131:194-203.
Naylor RL, Falcon WP, Goodman RM, Jahn MM, Sengooba T, Tefera H, Nelson RJ (2004). Biotechnology in the developing world: a case for increased investments in orphan crops. Food Policy 29(1):15-44.
Oduori C (2005). The importance and research status of finger millet in Africa. Presented at the McKnight Foundation Collaborative Crop Research Program Workshop on Tef and Finger Millet: Comparative Genomics of the Chloridoid Cereals at the Biosciences for East and Central Africa (BECA). Nairobi, Kenya, 28 - 30 June 2005.
Ogada MJ, Mwabu G, Muchai D (2014). Farm technology adoption in Kenya: a simultaneous estimation of inorganic fertilizer and improved maize variety adoption decisions. Agricultural and Food Economics 2(1):12.
Ogada MJ, Nyangena W, Yesuf M (2010). Production Risk and Farm Technology Adoption in The Rain–Fed, Semi–Arid Lands of Kenya. African Journal of Agricultural and Resource Economics 4(1):154-174.
Olwande J, Sikei G, Mathenge M (2009). Agricultural technology adoption: A panel analysis of smallholder farmers' fertilizer use in Kenya. CEGA Working Paper Series No. AfD-0908. Centre of Evaluation for Global Action. University of California, Berkeley https://escholarship.org/uc/item/9666220j
Östberg W (2015). Life among the Marakwet. Kenya Past and Present (42):53-67.
Padulosi S, Hodgkin T, Williams JT, Haq N (2002). 30 Underutilized crops: trends, challenges and opportunities in the 21st century. Managing plant genetic diversity, 323 p.
Padulosi S, Thompson J, Rudebjer P (2013). Fighting poverty, hunger and malnutrition with neglected and underutilized species: Needs, challenges and the way forward. Bioversity International https://cgspace.cgiar.org/bitstream/handle/10568/68927
Pierpaoli E, Carli G, Pignatti E, Canavari M (2013). Drivers of precision agriculture technologies adoption: A literature review. Procedia Technology 8:61-69.
Pingali PL (2012). Green Revolution: Impacts, limits, and the path ahead. Proceedings of the National Academy of Sciences 109(31):12302-12308.
Pingali P (2017). The Green Revolution and Crop Diversity (Chapter 12). In: D. Hunter, L. Guarino, C. Spillane, and P. McKeown (Edition) Handbook of Agricultural Biodiversity. New York: Routledge.
Rockström J, Kaumbutho P, Mwalley J, Nzabi A, Temesgen M, Mawenya L, Damgaard-Larsen S (2009). Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. Soil and Tillage Research 103(1):23-32.
Rogers EM (2004). A prospective and retrospective look at the diffusion model. Journal of Health Communication 9(S1):13-19.
Saka J, Lawal B (2009). Determinants of adoption and productivity of improved rice varieties in southwestern Nigeria. African Journal of Biotechnology 8(19):4923-4932.
Tadele Z (2009). Role of orphan crops in enhancing and diversifying food production in Africa. Paper presented at the African Technology Development Forum Journal. 6(3):9-15. https://www.syngentafoundation.org/file/2531/download?token=QXJxJDnK
Tadele Z (2014). Role of crop research and development in food security of Africa. International Journal of Plant Biology and Research 2(3):1-7.
Tadele Z, Assefa K (2012). Increasing food production in Africa by boosting the productivity of understudied crops. Agronomy 2(4):240-283.
Teklewold H, Kassie M, Shiferaw B (2013). Adoption of multiple sustainable agricultural practices in rural Ethiopia. Journal of Agricultural Economics 64(3):597-623.
Temesgen F, Emana B, Mitiku F, Gobana E (2017). Application of multivariate probit on determinants of sesame farmers market outlet choices in Gimbi District, Ethiopia. African Journal of Agricultural Research 12(38):2830-2835.
Thilakarathna M, Raizada M (2015). A review of nutrient management studies involving finger millet in the semi-arid tropics of Asia and Africa. Agronomy 5(3):262-290.
Toenniessen G, Adesina A, DeVries J (2008). Building an alliance for a green revolution in Africa. Annals of the New York Academy of

Sciences 1136(1):233-242.

Triomphe B, Floquet A, Kamau G, Letty B, Vodouhe S, Ng'ang'a T, Bridier B (2013). What does an inventory of recent innovation experiences tell us about agricultural innovation in Africa? The Journal of Agricultural Education and Extension 19(3):311-324.

Wairimu E, Obare G, Odendo M (2016). Factors affecting weather index-based crop insurance in Laikipia County, Kenya. Journal of Agricultural Extension and Rural Development 8(7):111-121.

Wainaina P, Tongruksawattana S, Qaim M (2016). Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya. Agricultural Economics 47:351-362.

Walker T, Alwang J (2015). Crop improvement, adoption and impact of improved varieties in food crops in Sub-Saharan Africa: CABI.

Wossen T, Abdoulaye T, Alene A, Haile M, Feleke S, Olanrewaju A, Manyong V (2017). Impacts of extension access and cooperative membership on technology adoption and household welfare. Journal of Rural Studies 54:223-233.

Yapa L (1993). What are improved seeds? An epistemology of the Green Revolution. Economic Geography 69(3):254-273.

Vol. 13(36), pp. 1901-1906, 6 September, 2018
DOI: 10.5897/AJAR2018.13266
Article Number: FC5875258425
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Productive capacity of *Brachiaria brizantha* (Syn. *Urochloa brizantha*) cv. Marandu subjected to liming and nitrogen application

Raimundo Nonato Vieira Teixeira[1], Carlos Eduardo Pereira[2], Hamilton Kikuti[3], Bruno Borges Deminicis[1*] and Thiago Pereira Valente[4]

[1]Faculty of Agrarian Sciences, Federal University of Amazonas, Humaitá - Amazonas, Brazil.
[2]Agroforestry Science Center, Federal University of Southern Bahia, Ilhéus - Bahia, Brazil.
[3]Institute of Agrarian Sciences Federal University of Uberlândia, Uberlândia - Minas Gerais, Brazil.
[4]Goiano Federal Institute, Campus Posse, Posse - Goiás, Brazil.

Received 24 May, 2018; Accepted 30 July, 2018

This work aims to evaluate production of *Brachiaria brizantha* (Syn. *Urochloa brizantha*) cv. Marandu subjected to liming and nitrogen fertilization on climatic conditions in the municipality of Humaitá State of Amazonas, Amazônia, Brazil. For both, pot experiment with soil after sowing was kept in a greenhouse at the Institute of Agriculture and Environmental Education (IEAA / UFAM). Part of the soil pots was incubated with limestone while the remainder of the vessels is used without liming ground. Different nitrogen levels (0, 100, 0 200 and 300 kg.ha^{-1}) were also applied in a 2x4 factorial design with four replications. To assess the growth and development of plants, number of tillers, along with weight of fresh and dry matter were used in the first, second and third cut. Liming enables further growth and development of *B. brizantha* (Syn. *U. brizantha*) plants and enhances the plant response to nitrogen.

Key words: Urea, pasture, dry matter, limestone.

INTRODUCTION

An important characteristic of Brazilian cattle breeding is that most of their herd is grazed (Ferraz and Felício, 2010). Currently, Brazil uses 167.5 million hectares of cattle pasture, with a herd of 222 million cattle (Anuário, 2017).

According to Ministério da Agricultura, Pecuária e Abastecimento - MAPA (2015), some 30 million hectares of pasture in Brazil are currently undergoing some degree of degradation, and the correct use of technologies and adoption of good agricultural practices would make it

*Corresponding author. E-mail: brunodeminicis@gmail.com Tel: 55-73-3214-3288.

possible to reinsert these areas into the productive process. The occupation of this type of areas would imply a lesser need for the opening of new areas for agriculture and livestock (Borghetti et al., 2017).

The genus *Brachiaria* is cultivated more among the forages cultivated in Brazil because it presents advantages such as strong adaptation to the acid soils, hence low fertility besides providing high yield of dry matter (DM) per hectare. Despite the economic importance of this genus, there are frequent failures in the production system of these pastures, by adopting techniques and strategies that are not appropriate (Moreira et al., 2009).

The low availability of nutrients in pasture exploitation is undoubtedly one of the main factors that interfere both in the productivity level and the quality of the forage; thus, supply of nutrients in adequate quantities and proportion are of fundamental importance in the productive process of pastures (Benett et al., 2008).

Nitrogen is the main nutrient for maintaining the productivity of forage grasses (Werner, 1994), and as part of the chlorophyll molecule, participates directly in photosynthesis (Sousa and Lobato, 2004). Urea is currently the most used nitrogen fertilizer in Brazil and in the world, corresponding to about 60% of fertilizers commercialized, due to the advantages offered as ease of manufacture, low production costs, and higher concentration of N (Chagas et al., 2017).

The objective of this work was to evaluate the productive capacity of *Brachiaria brizantha* (Syn. *Urochloa brizantha*) cv. Marandu submitted to liming and nitrogen fertilization, under climatic conditions of the Humaitá-AM municipality, Brazil.

MATERIALS AND METHODS

The experiment was conducted in Humaitá - AM, Brazil (latitude 07º30'22 "south and longitude 63º01'15" west,) from July 2012 to February 2013 under greenhouse conditions. The climate of the region, according to Koppen classification, is tropical rainy type (monsoon type rainfall), presenting a dry period of short duration (Am), temperatures ranging from 25 to 27°C and average annual rainfall of 2500 mm, with rainy season beginning in October and extending until June along with relative humidity of 85-90%. Seeds of *B. brizantha* cv. Marandu were planted in 15 dm^3 pots (Dimensions: 28 cm wide Top, 28 cm high, 25 cm wide bottom) with a typical dystrophic red-yellow Latosol (LVAdf (Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA, 2006), collected from the 0-20 cm layer in UFAM-Humaitá *Campus*, which were submitted to chemical analysis (Table 1). After germination, two slabs were performed every five days until five plants were left per pot. The parameters used for plant selection includes homogeneity, position inside the pot and size.

According to the results presented in Table 1, the need for liming was determined using 45% for V_2 of the formula, according to Werner et al. (1996). After application of the "filler" limestone, the soil was incubated for 30 days. Following this period, seed sowing of Marandu was carried out, and after 15 days, the thinning of the seedlings was done leaving only five per pot.

Table 1. Results of the chemical analysis of soil samples used as substrate for the growth of *Brachiaria brizantha* under greenhouse conditions.

Characteristic	Value	Rating*
C (dag kg^{-1})	1.49	Medium
M.O (dag kg^{-1})	2.57	Medium
P (mg dm^{-3})	2.00	Very low
K (mg dm^{-3})	17.00	Low
Ca ($cmol_c$ dm^{-3})	0.86	Low
Mg ($cmol_c$ dm^{-3})	0.08	Very low
Al ($cmol_c$ dm^{-3})	3.68	Very high
H+Al ($cmol_c$ dm^{-3})	7.89	High
pH (em H_2O)	4.09	Very high acidity
SB ($cmol_c$ dm^{-3})	1	Low
t ($cmol_c$ dm^{-3})	4.68	Good
T ($cmol_c$ dm^{-3})	8.89	Good
V (%)	11,3	Very low
m (%)	78.6	Very high
Fe (mg dm^{-3})	134	High
Zn (mg dm^{-3})	0.6	Low
Mn (mg dm^{-3})	1.01	Very low
Cu (mg dm^{-3})	1.09	Medium

U.M = Unit of measurement; M.O = Organic Matter. * According to Ribeiro et al (1999).

Four doses of Nitrogen (0; 100; 200 and 300 $kg.ha^{-1}$), divided into three coverage applications were used: the first dose after thinning the plants (cut to uniformity at 10 cm from the soil), second dose after first cut and the third dose was performed after the second cut of the plants. The nitrogen was applied in the form of urea.

Single doses of 120 $kg.ha^{-1}$ of P_20_5 and 60 $kg.ha^{-1}$ of K_2O were applied in all treatments. Three cuts were performed within a 45-day period, with first interval starting at 45 days after cutting the plants and applying the nitrogen. The plants were evaluated for tillering number, green biomass and shoot dry matter. To determine the green biomass, the shoot was cut at a height of 10 cm from the soil surface and then weighed. To evaluate the dry biomass, the samples were packed in paper bags and kept in an oven at 65ºC until reaching constant weight. Three pots were used per treatments per replicate.

The experimental design was randomized complete block with the treatments arranged in a 2x4 factorial scheme (with and without liming and doses 0, 100, 200 and 300 $kg.ha^{-1}$ of nitrogen), with four replications. The results were subjected to analysis of variance and the means of liming factor and nitrogen doses was studied by means of the F test and the regression analysis, respectively. Sisvar computational package was used to perform the statistical analysis (Ferreira, 2000).

RESULTS

Liming significantly increased the number of tillers per plant and fresh and dry weights (Table 1) with a high degree of probability when soil acidity correction occurs

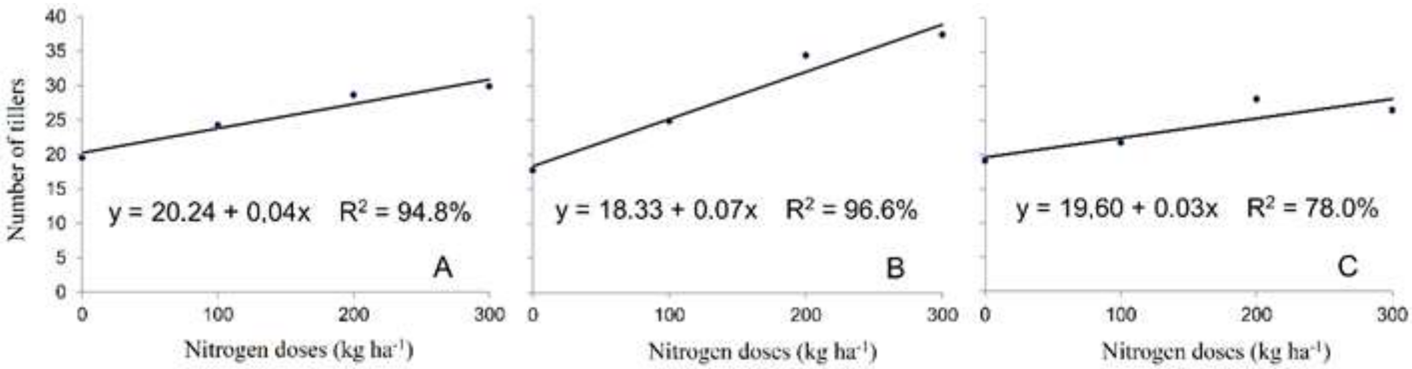

Figure 1. Results of the number of tillers per plant of *Marandu brachiaria* submitted to the first (A), second (B) and third (C) cuts after fertilization with different doses of nitrogen.

($CaCO_3$ e $MgCO_3$), taking into account the Ca: Mg ratio. There is a high increase in forage productivity due to improvements in the chemical, physical and biological properties of the soil (Freiria et al., 2008; Barreto et al., 2008) as well as in the nutritional balance of the plant (Oliveira, 2011).

In relation to the application of different nitrogen rates, the number of tillers was linearly increased in the first, second and third cuts, according to the increase of the applied nitrogen dose (Figure 1A, 1B and 1C), regardless of the liming.

Marques et al. (2016), studying the application of nitrogen doses in Massai guinea grass (*Panicum maximum*), showed that the rate of emergence of tillers, dry matter, protein content and crude protein increased linearly in the second and third cuts after the application of nitrogen. Also, the dose of 120 mg/dm³ presented the best results in relation to the absence of nitrogen fertilization, helping to obtain 16% of crude protein, 69% of neutral detergent fiber and 20 g of dry matter per pot, that is, 4 g per plant.

Pereira et al. (2011), working with Mombasa guinea grass (*P. maximum*) in three cultivated densities and fertilized with nitrogen, obtained 34.9 and 46.0% of tiller increase in relation to absence and presence of N (320 $kg.ha^{-1}$), respectively. According to Werner (1986), nitrogen is responsible for characteristics related to plant size, such as leaf size, stem size, tillering and development.

The results observed in the interaction between liming and nitrogen for the green biomass variable showed that there was a significant response (linear in nature), increasing according to the increase of nitrogen applied when limestone was applied (Figure 2A). Results for the same variable without liming showed that it tends to increase until the dose of nitrogen equivalent to 200 $kg.ha^{-1}$ and then begins to decrease as a function of the increase of the dose of nitrogen applied.

Cardoso et al. (2016) evaluated the effects of lime and nitrogen doses on Massai guinea grass. The limestone and nitrogen doses positively influenced the dry mass accumulation of the Massai guinea grass and the saturation by the maximum agronomic efficiency obtained in the estimated doses close to 587 $kg.ha^{-1}$ $year^{-1}$ of nitrogen and 5,796 $kg.ha^{-1}$ of limestone.

For the green biomass analyzed in the second and third cuts, there was no interaction between the liming and the application of nitrogen (Figures 2B and 2C). It was observed that when increasing the nitrogen dose from 200 $kg.ha^{-1}$, there was no continuity of the increase of green biomass of the plants in the second cut, as observed for smaller doses. This was probably due to the effects of urea (H^+) on soil acidification, since, while limestone increases base saturation, nitrogen caused a reduction in soil acidity, altering the need for soil acidity correction. Costa et al. (2008), studying doses and nitrogen sources in pasture of *Marandu* grass observed a linear increase in the production of green biomass with the application of increasing doses of nitrogen. However, the application of high doses of N increases the levels of Al_3^+, Organic Matter, Total Nitrogen, N-NO_3^- and N-NH_4^+ in the soil.

As observed for the green biomass in the first cut, a significant interaction between liming and nitrogen application was observed (Figure 3A). There was an increasing linear response of the dry biomass with the increase of nitrogen applied when liming was performed.

Results observed for the same variable without liming showed that it tends to increase up to the dose of nitrogen equivalent to 200 $kg.ha^{-1}$, reducing with the application of higher doses of nitrogen. Similar to that observed for the green matter in the second cut (Table 2), the dry matter of the plants was collected in the second cut, presenting a quadratic tendency in relation to the application of nitrogen, and with a reduction in the increase of the dry matter in high doses.

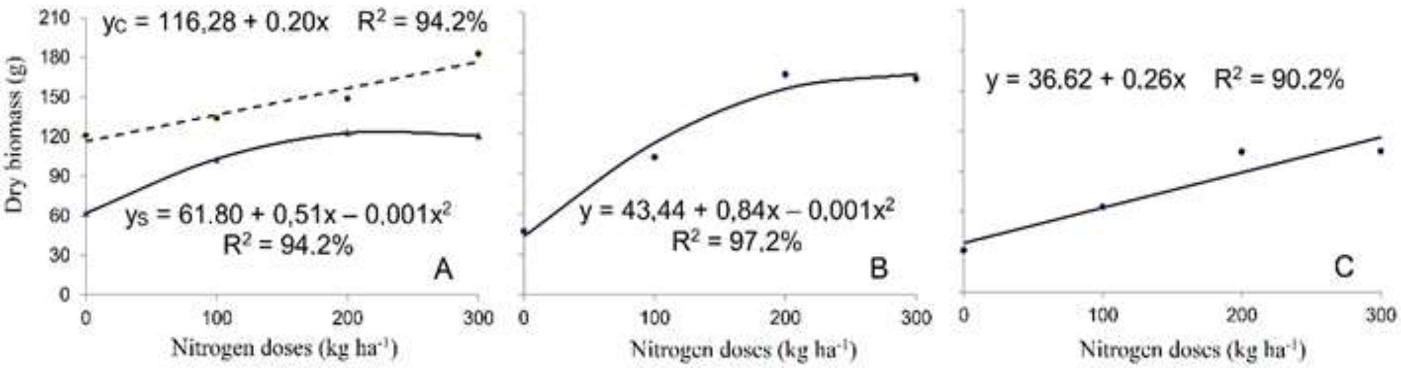

Figure 2. Results of the green biomass per pot of submitted to the first (A), second (B) and third (C) cuts after fertilization with different doses of nitrogen independently of liming (y), with (yC) and without (yS) application of limestone.

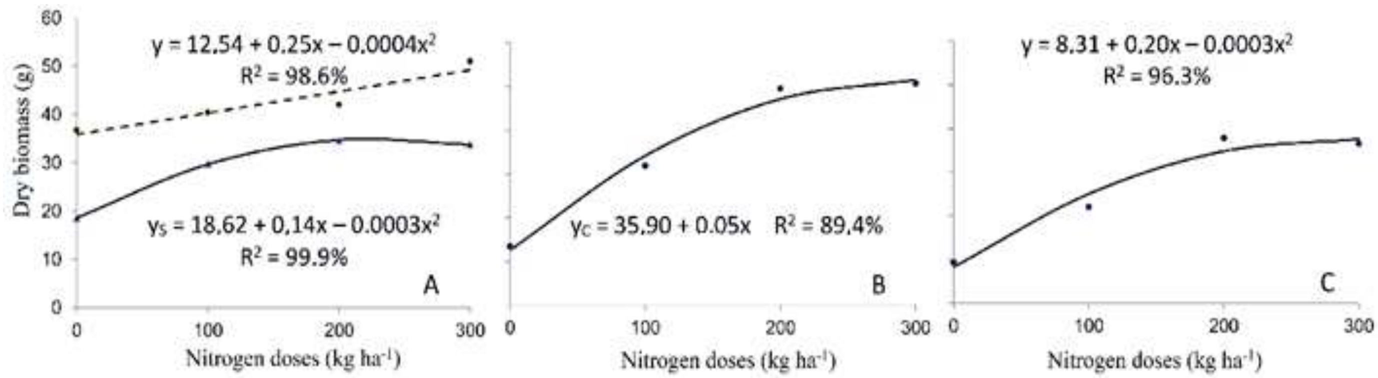

Figure 3. Results of dry biomass of *Marandu brachiaria* submitted to the first (A), second (B) and third (C) cuts after fertilization with different doses of nitrogen independently of liming (y), with (yC) and without (yS) application of limestone.

Table 2. Results of the number of tillers in the first - 1C, second cut - 2C ad third cut - 3C, green biomass in the first - GB1 (g/pot), in second – GB2 and third cut – GB3, and dry matter (%) in the first (DM1), second (DM2) and third cut (DM3).

Liming	1C	2C	3C	GB1	DM1	GB2	DM2	GB3	DM3
Without	22 b	26 b	27 b	86 b	25 b	95 b	29b	64b	22b
With	29a	32 a	33 a	130 a	33 a	142 a	44a	88a	31a
CV (%)	12.3	14.4	11.4	15.6	12.8	25.0	21.4	29.1	30.4

*Means followed by the same letter in the column do not differ significantly from each other by the F test at the 5% probability level.

Primavesi et al. (2004) reported similar effects on base saturation by lime and nitrogen in a study with signal grass *B. decumbens (Urochloa decumbens)* cv. Basilisk). It is pertinent to point out that in the first cut there was interaction of the application of limestone and nitrogen; a fact that on the contrary, was not reported by Elyas et al. (2006), in Pojuca grass (*Paspalum atratum* Swalen cv. Pojuca) during the first three cuts. However, the same authors concluded that the application of 200 $mg.dm^{-3}$ of N is indispensable for a good growth and good dry matter production of the Pojuca grass, which is not necessary to raise the level of soil base saturation above 40%.

It’s important to point out that *Brachiaria* response to the application of limestone depends on the initial V% of the soil. In the present study, the initial V% was 11%; even if it was low, it could supply the plant with the nutrients Ca and Mg, because Cruz et al. (1994) obtained response from *Brachiaria* to liming on soil with very low

V% (4%). In addition to this fact, another aspect that is important to explain the absence of the response of the forage to the application of limestone, which is the time of reaction of the limestone, may have been insufficient since the use of limestone dose was used at most V equal to 45%.

The evaluated variables were not significantly affected by limestone application. Rodrigues et al. (2005), working with *Brachiaria decumbens* (V = 32%) also did not observe effect on dry matter production. Other authors also reported the lack of response of forages to the application of limestone, such as in Tobiatã grass (Luz et al., 2002) and Pojuca grass (Elyas et al., 2006).

Kawatoko et al (2012), evaluating the response of *B. decumbens* to the application of limestone, nitrogen and zinc in the production of dry matter during four cuts verified the response of *B. decumbens*. The application of limestone occurred only in the fourth cut when in the presence of nitrogen fertilization; whereas in the application of nitrogen, it gave immediate effect, increasing the dry matter yield of the forage during the first three cuts. This occurred probably because the *Marandu* grass is more demanding in soil fertility than the Basilisk grass (Santos et al., 2009).

Conclusions

Application of 200 $kg.ha^{-1}$ of N is indispensable for good growth and good biomass production of *B. brizantha* (Syn. *U. brizantha*) cv. Marandu, and is unnecessary for raising the saturation level by soil bases above 45%. The evaluated variables were not significantly affected by limestone application.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Anuário Brasileiro da Pecuária (2017). Santa Cruz do Sul: Gazeta, 96p.

Barreto PM, Santos AC, Guimarães Júnior MPA, Brito SS, Terra TGR, Leal TCA (2008). Relações Ca:Mg nas características agronômicas do *Brachiaria brizantha* cv. MG-4. Pubvet 2:38.

Benett CGS, Yamashita OM, Koga PS, Silva SK (2008). Resposta da *Brachiaria brizantha* cv. marandu a diferentes tipos de adubação Revista de Ciências Agro- Ambientais 6(1):13-20.

Borghetti JR, Silva WLC, Nocko HR, Loyola LN, Chianca GK (2017). Agricultura Irrigada Sustentável no Brasil: Identificação de Áreas Prioritárias. FAO, Brasília 243 p.

Cardoso S, Volpe E, Macedo MCM (2016). Effect of nitrogen and lime on Massai grass subjected to intensive cutting. Pesquisa Agropecuária Tropical Goiânia 46(1):19-27.

Chagas PHM, Gouveia GCC, Costa GGS, Barbosa WFS, Alves AC (2017). Volatilização de amônia em pastagem adubada com fontes nitrogenadas. Revista de Agricultura Neotropical 4(2):76-80.

Costa KAP, Faquin V, Oliveira IP, Rodrigues C, Severiano EC (2008). Doses e fontes de nitrogênio em pastagem de capim-marandu: alterações nas características químicas do solo. Revista Brasileira de Ciência do Solo 32(4):1591-1599.

Cruz MCP, Ferreira ME, Luchetta S (1994). Efeito da calagem sobre a produção de matéria seca de três gramíneas forrageiras. Pesquisa Agropecuária Brasileira 29:1303-1312.

Elyas ACW, Pinto JC, Furtini Neto AE, Morais AR (2006). Nitrogênio e saturação por bases no desempenho do capim-pojuca (*Paspalum atratum* Swalen cv. Pojuca) cultivado em vasos. Ciencia e Agrotecnologia 30:554-561.

Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA (2006). Centro Nacional de Pesquisa do Solo. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro, Embrapa Solos, 306p.

Ferraz JBS, Felício PED (2010). Production systems - an example from Brazil. Meat Science 84(2):238-243.

Ferreira DF (2000). Análises estatísticas por meio do SISVAR para Windows versão 4.0. In: Reunião Anual da Região Brasileira da Sociedade Internacional de Biometria, 45, São Carlos, SP. Programas e Resumos. São Carlos: UFSCAR. P. 235.

Freiria AC, Mantovani JR, Ferreira ME, Cruz MCP, Yagi R (2008). Alterações em atributos químicos do solo pela aplicação de calcário na superfície ou incorporado. Acta Scientarum. Agronomy 30(2):285-291.

Kawatoko M, Fernandes FM, Prado RM, Isepon OJ (2012). Efeito imediato de calcário, nitrogênio e zinco na produção de matéria seca de *Brachiaria decumbens*. Terra Latinoam 30(1):81-87.

Luz PHC, Herling VR, Braga GJ, Vitti GC, Lima CG (2002). Tipos e doses de calcário nas características agronômicas de *Panicum maximum* Jacq. cv. Tobiatã em função dos métodos de aplicação. Scientia Agricola 59:155-159.

– Ministério da Agricultura, Pecuária e Abastecimento MAPA (2015). Projeção do Agronegócio Brasileiro 2014/15 a 2024/2025. Brasília: 2015.

Marques MF, Romualdo LM, Martinez JF, Lima CG, Lunardi LJ, Luz PHC, Herling VR (2016). Momento de aplicação do nitrogênio e algumas variáveis estruturais e bromatológicas do capim-massai. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 68(3):776-784.

Moreira LM, Martuscello JA, Fonseca DM, Mistura C, Morais RV, Ribeiro Júnior JI (2009). Perfilhamento, acúmulo de forragem e composição bromatológica do capim-braquiária adubado com nitrogênio. Revista Brasileira de Zootecnia 38:1675-1684.

Oliveira ECA (2011). Balanço nutricional da cana-de-açúcar relacionada a adubação nitrogenada. Tese de Doutoramento. Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba, Brasil 213 p.

Pereira VV, Fonseca DM, Martuscello JA, Braz TGS, Santos MV, Cecon PR (2011). Características morfogênicas e estruturais de capim-mombaça em três densidades de cultivo adubado com nitrogênio. Revista Brasileira de Zootecnia 40(12):2681-2689.

Primavesi O, Corrêa LA, Freitas AR, Primavesi AC (2004). Calagem em pastagem de *Brachiaria decumbens* recuperada com adubação nitrogenada em cobertura. São Carlos: Embrapa Pecuária Sudeste, (Circular técnica, 37).

Ribeiro AC, Guimarães PTG, Alvarez VH (1999). Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5ª aproximação. Viçosa - MG: UFV. pp. 25-32.

Rodrigues RC, Mattos WB, Pereira WLM, Lavres Jr J, Mattos WT (2005). Carboidratos não-estruturais, nitrogênio total e produção de massa seca de raiz do capim-braquiária em função de doses de enxofre, nitrogênio e calcário. B. Ind. Animal 62:71-78.

Santos L, Bonomo P, Silva VB, Patês NMS, Silva CCF, Pires AJV (2009). Características morfogênicas de Braquiárias em resposta a diferentes adubações diferentes adubações. Acta Scientiarum Agronomy 31(1):221-226.

Sousa DMG, Lobato E (2004). Adubação com nitrogênio. In: Sousa, D.M.G.; Lobato, E. (Eds.) Cerrado – correção do solo e adubação. 2.ed. Brasília: EMBRAPA. pp. 129-145.

Werner JC (1986). Adubação de pastagens. Nova Odessa: Instituto de Zootecnia 49 p. (Boletim Técnico, 18).

Werner JC (1994). Adubação de pastagens de Brachiaria spp. In:

Simpósio sobre manejo da pastagem, 11., Piracicaba, 1994. Anais... Piracicaba: FEALQ pp. 209-223.
Werner JC, Paulino VT, Cantarella H, Andrade NO, Quaggio JA (1996). Forrageiras. In: Raij, B. van; Cantarella, H.; Quaggio, J.A.; Furlani, A.M.C. Recomendações de adubação e calagem para o Estado de São Paulo. 2.ed. Campinas: Instituto Agronômico de Campinas, Fundação IAC. pp. 263-273.

Vol. 13(36), pp. 1907-1914, 6 September, 2018
DOI: 10.5897/AJAR2017.12910
Article Number: 5FA078658427
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Soil nitrate, phosphorus and potassium concentration after four years of liquid swine manure application on Tifton 85

Tangriani Simioni Assmann[1*], Alceu Luiz Assmann[2], Laércio Ricardo Sartor[1], and Talyta Zortéa[1]

[1]Federal Technological University of Paraná, UTFPR, Dois Vizinhos, PR, Brasil.
[2]Agronomic Institute of Paraná, IAPAR, Pato Branco, PR, Brasil.

Received 29 November, 2017; Accepted 21 August, 2018

One major problem of swine production is the huge volume of manure generated; this involve difficulties in proper handling of the residue when applied to the soil, given that such elements can be toxic to the environment. This study examined the vertical movement of the P, K and mineral N in the soil profile cultivated with *Cynodon dactylon* cv. Tifton 85 which was submitted consecutively to rates of Liquid Swine Manure (LSM) application (four years). The experiment was done using a randomized block design with four replications in a split-plot arrangement, where the whole plots were semiannual applications (November, 2002 to September, 2006) of increasing levels of LSM (0, 30, 60, 90, 120 and 180 m^3 ha^{-1}); while the sub-plots were the soil samples at different depths (0-10, 10-20, 20-40, and 40-60 cm). The $N\text{-}NO_3^-$ leaching was observed when application of LSM exceeded 90 m^3 ha^{-1} twice annually or during the year, suggesting a limit level for fertilizer on Tifton 85 pastures. Phosphorous and potassium accumulation was observed at higher LSM rate, mainly at the 0-10 cm soil layer since the soil P levels increased up to the highest evaluated depth at the 180 m^3 ha^{-1} LSM level. LSM meets the Tifton 85 nutritional requirement regarding N, P and K when applied semi-annually at the rate of 90 m^3 ha^{-1} without causing pollution effects; although the grass production responds up to 180 m^3 ha^{-1} levels.

Key words: *Cynodon dactylon*, environmental contamination, mineral nitrogen, organic fertilizers.

INTRODUCTION

Swine production is an important part of the Brazilian agribusiness that consuming large quantities of grains and water, with daily water consumption of 9.05 to 22.05 L^{-1} pig^{-1} (Nardi, 2009). Consequently, this activity produces large quantities of residue, since each liter of ingested water generates 0.6 L^{-1} of liquid swine manure (Oliveira, 1993); often times, distributed in small areas. Majority of swine growers in the country are smallholders (Mohedano et al., 2014). It is important to determine the Liquid Swine Manure (LSM) effect as a soil pollutant under different crops in order to illustrate the rates its use would be acceptable long term (Scherer et al., 2010; Maccari et al., 2016).

LSM is a nutrient and organic matter source for

*Corresponding author. E-mail: tangriani@utfpr.br.

cultivated soils, and lots of plant production systems can benefit from the agriculture cycling of swine manure (Couto et al., 2013). Its usage in pastureland, if conducted properly, can contribute to the system's sustainability, given that it is capable of increasing production and quality of pastures (Vielmo et al., 2011). In addition, lack of fertilization is one of the major factors contributing to the degradation of pasture land in Brazil and the LMS applications can remediate this kind of degradation.

A significant amount of the macro and micronutrients ingested by the swine are excreted in dung and urine (Berenguer et al., 2008). If the organic fertilization is cautious, it can replace chemical fertilization of crops in part or whole (Ourives et al., 2010). However, when used irrationally, disregarding soil-support capability with no application rate limits, the LSM can become a great source of pollution for water springs (Domene et al., 2007).

Approximately 70% of the N present in the LSM stocked in dunghills is in ammoniacal form (Scherer et al., 1996). When applied to the soil, it is oxidized to nitrate by nitrifying bacteria (Whitehead, 1995) in a relatively fast pace (Aita et al., 2006). Therefore, highly productive pastures like Tifton 85 can exhibit higher utilization rates of the mineral N present in the soil arising from the LSM application. Aita et al. (2006) observed higher mineral N in soils under fallow compared to soils cultivated with black oats under the 80 m^3 ha^{-1} of LSM rate. This behavior can be maximized by the use of perennial pastures like the *Cynodon* ones.

Nevertheless, the swine manure application can be a possible source of soils and water contamination through nitrate (NO_3^-) (Puig et al., 2017). This can result from excessive fertilizer application in the soil, independent of the fertilizer type, which can be dangerous to both human and animal health (Robertson, 2005; Bryan et al., 2012). Various studies show N mobility to have higher depths when cultivated with annual crops (Ceretta et al., 2010). Such mobility can vary for soils under perennial forage species given their root system structure, greater cultivation period, and pasture utilization.

Besides N, elements that are deeply required by the cultures like phosphorus and potassium are added to the soil when the LSM is applied and are absorbed by the plants when available (Ceretta et al., 2010) or can be lost by leaching, primarily P, which is the main element associated with eutrophication problems (Sharpley et al., 2001; Gatiboni et al., 2015).

Therefore, knowledge on N, P and K behavior in the soil profile under different rates and constant application of LSM is important to support the use of this organic fertilizer in pastures to ensure there is no environmental contamination. The research aim to evaluate the vertical movement of nitrate and ammonium as well as the P and K behavior in a soil cultivated with perennial summer grass (*Cynodon dactylon* cv. Tifton 85) under a semiannual application. This was done within four years of increasing rates of LSM and the forage production response of the pasture.

MATERIALS AND METHODS

Study area

The research was conducted from November 2002 to September 2006, in an area located at 26° 07' S and 52° 41' W , at 700 m a.s.l, under a climatic condition that transits from Cfb (temperate climate) to Cfa (subtropical climate), according to the KÖPPEN climate classification (Maak, 1968). The precipitation regime in the past 10 years was on an average of 2000 mm. The soil is classified as a Dystrophic Red Oxisol (Ferritic Ferralsols, according to classification World Reference Base for Soil Resources, WRB, 2014). The soil is on a hilly topography with a clay texture and under a 10 year no-tillage planting system.

Sampling and experiment designs

Sprigs of *Cynodon* sp cv. Tifton 85 were planted in November 2002. The first LSM application was in March 2003, when the pasture was established and subsequent applications happened semi-annually; totaling six LSM applications with rates of 0, 30, 60, 90, 120 and 180 m^3 $ha^{-1.}$

The experimental design was in a randomized block with four repetitions in a split-plot. The treatments consisted of increasing LSM rates (0, 30, 60, 90, 120 and 180 m^3 ha^{-1}) for the whole plots and the sampling depths as the sub-plots. In September 2006, soil samples were collected at different depths of (0-10, 10-20, 20-40, and 40-60 cm) to evaluate the $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, P and K concentrations. In 2004, P and K concentrations were evaluated under the same depths. Soil samples were collected at eight different sites per plot, which were later dried at 55°C for 72 h, and the $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$ concentrations were determined through the method described by Pavan and Miyazawa (1996). The K and P contents were extracted by the double acid method Melich-1, and later flame photometer, and the P determined the K by atomic absorption spectrophotometry.

The dry matter production of Tifton 85 evaluation started in November 2003 when the plant canopy in each plot was 30 cm high on average. Samples were cut to a 10 cm stubble, from a 0.25 m^2. Four subsamples were taken in each plot, and mixed to represent one plot sample, which were dried at 55°C in a forced-air oven to constant weight. Forage production was calculated (kg ha^{-1} de MS) annually (from January to December of each year). Winter cuts were not performed due to minimal plant growth.

Statistical analysis

An analysis of variance multifactorial was conducted. The variables considered homogeneous had their treatments evaluated with the F-test. When the results were significant at 5%, polynomial regressions were fitted for LSM rates, versus $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, phosphorus and potassium concentration, for different depths, seeking the model with higher significance level.

RESULTS AND DISCUSSION

The interaction between LSM rates and sample depth

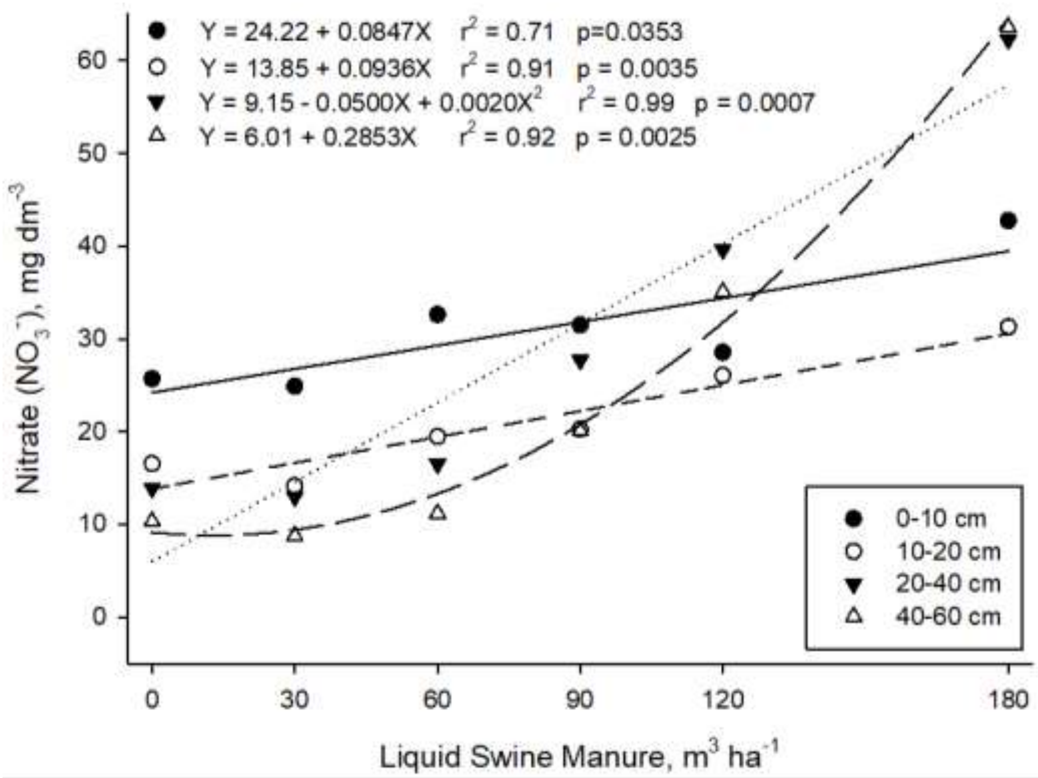

Figure 1. Soil nitrate concentration at different depths as a function of Liquid Swine Manure application rates.

(Figure 1) was observed for $N\text{-}NO_3^-$ soil concentration. After 46 months of the experiment establishment and six semiannual LSM applications according to stated rates, the highest $N\text{-}NO_3^-$ concentrations were observed in the topsoil layer (0-10 cm) using LSM application of 90 m³ ha^{-1}. For higher rates, $N\text{-}NO_3^-$ accumulation was observed for layers from 20 to 60 cm depth, which indicates $N\text{-}NO_3^-$ leaching potential for LSM applications from 90 to 180 m³ ha^{-1} (Figure 1). Therefore, these rates of LSM are not recommended for areas under *C. dactylon* cv. Tifton 85 cultivation.

The higher nitrate concentration in the 10 to 60 cm depth, as a consequence of the higher LSM rates, may result in contamination of the water table which depends on the leaching rate of $N\text{-}NO_3^-$ in the soil profile. The leaching rate of $N\text{-}NO_3^-$ is a consequence of the volume of infiltrated water and Tifton 85 root system's ability to absorb $N\text{-}NO_3^-$ in the deep layers.

Basso et al. (2005) observed higher $N\text{-}NO_3^-$ losses through percolated water when the LSM rate applied increased from 0 to 80 m^3 ha^{-1}, exposing that 40 m^3 ha^{-1} rates do not present $N\text{-}NO_3^-$ leaching concern. Aita et al. (2006) have observed evidence of $N\text{-}NO_3^-$ leaching for layers beyond 60 cm depth using LSM at 80 m^3 ha^{-1} with annual species (corn, weeds and black oat). Sacomori et al. (2016) verified that high doses of DLS applied to the soil surface (200 m^3 ha^{-1}) contributed to the leaching of nitric N at the depths of 40 and 80 cm.

Nikiéma et al. (2013), when assessing the application of DLS in wheat cultivation up to the dose of 68 m^3 ha^{-1} in a sandy soil, verified that nitrate leaching is mainly related to annual rainfall. In years where rains were above average, DLS N losses extended to 29.3%. In addition to the climatic conditions, the soil characteristics determine the intensity of the leaching process occurrence, since it is inversely proportional to the number of adsorption sites (Mota et al., 2015). For the research presented here, this fact can also be stated for rates over 90 m^3 ha^{-1} applied semiannually, indicating that Tifton 85 may present higher potential for $N\text{-}NO_3^-$ utilization when LSM is used. Other studies evidenced the high potential of nitrogen utilization of organic fertilizers using grasses. Franzluebbers and Stuedemann (2005), after 5 years of application of different nitrogen sources (organic and inorganic), observed that there was little nitrate loss through leaching, despite the application of 200 kg N ha^{-1} $year^{-1}$; this indicates that the uptake of N by bermudagrass (*C. dactylon* (L.) Pers) was efficient to reduce the losses, mainly by the habit of vigorous growth of the roots in a way that potentiates the use of this element by the plants.

The $N\text{-}NH_4^+$ concentration were fitted to a positive linear model to the LSM rates applied to the soil (Figure 2), with an increase of 2.3 mg dm^{-3}, from the lower to the

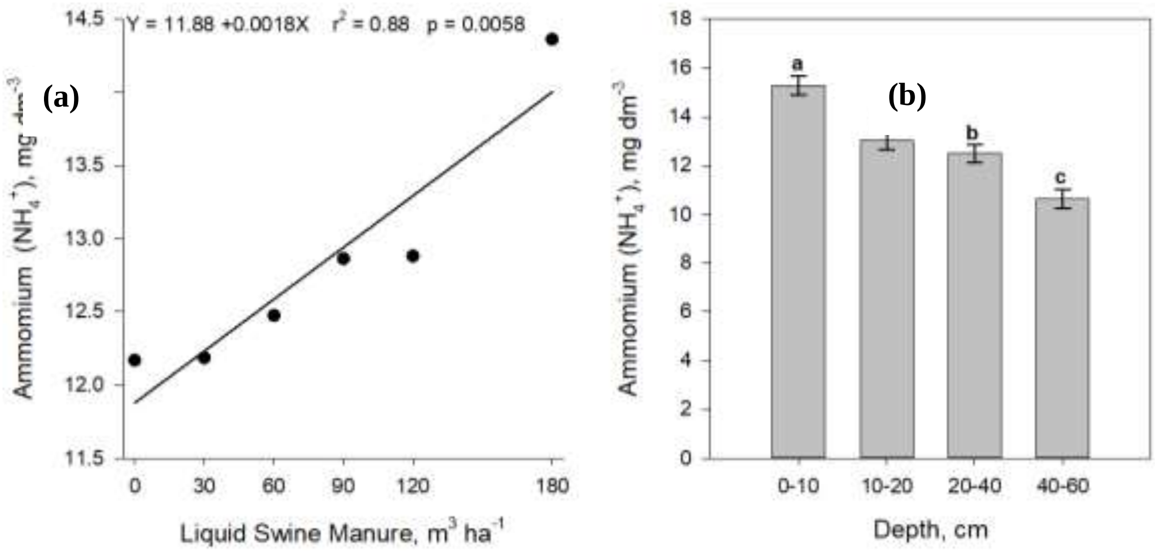

Figure 2. Soil ammonium concentration as a function of LSM application rates (Figure 2A) and for different soil depths (Figure 2B).

higher LSM rate without considering the high fertilizer amount. This is justified by the fast nitrification of the ammoniacal N applied via LSM (Aita et al., 2006).

Higher $N\text{-}NH_4^+$ concentrations were observed at the topsoil layer (0 to 10 cm), significantly higher from the deeper layers of the soil profile; with lower $N\text{-}NH_4^+$ concentration at the 40 to 60 cm layer (Figure 2). This $N\text{-}NH_4^+$ increment with higher LSM rates and the higher concentration at the topsoil layer were expected, since the ammonium, being a cation, is stable in the soil, and is adsorbed by the soil negative charges; consequently, presenting low mobility (Oliveira et al. 2011). Therefore, ammonium does not contribute extensively to contamination problems of subsurface water.

The effect of the interaction between LSM application rate and sample depth was not observed (Figure 3) for potassium concentration in year 2004 and 2006. The highest K concentration of the experiment was observed under the 180 m^3 ha^{-1} rate, in the topsoil layer, with significant variations in the 0 to 10 cm layer and 10 to 20 cm due to LSM applied rates. During the two evaluation years, K concentration was higher in the topsoil layer and higher accumulations were observed with higher LSM rates.

These results are not the same with those found by Ceretta et al. (2003), who conducted an experiment in a Chromic Orthic Alfisol with low clay percentage under natural grassland, and observed decrease of available K quantity in the topsoil layer with LSM application, when compared with the control treatment. Results from this study suggest that the behavior of K present in the LSM in Dystrophic Red Oxisol with high clay percentage differs from its behavior in sandy soils. Queiroz et al. (2004), in a Red-Yellow Sposol in Rio Grande do Sul also observed exchangeable K accumulation in the topsoil layer when swine manure was applied.

Therefore, it is possible to state that there is a tendency of higher K accumulation in the topsoil layers in soils with high clay percentage, when increasing LSM rates are applied; leaving the nutrient available to the pasture or to leaching. When the LSM is applied at 90 m^3 ha^{-1}, the K concentration at the 0-20 cm depth (Figure 3), depth at which analysis and correction of the soil under pastures are recommended, is within that recommended for high productivity forage species, such as Tifton 85.

K accumulation in the soil was not observed from 2004 to 2006 in the respective LSM rates (Figure 3). The only difference observed was between LSM rates and sample depths. Scherer et al. (2007) did not observe LSM rate effects on the K concentration in the soil with LSM application from 0 to 115 m^3 ha^{-1} for three years, leading to decrease of K concentration with depth; which is similar to this research. Lourenzi et al. (2016) observed increases in the available K content, mainly in the superficial layers of the soil after 6 years of applying organic pig waste (DLS + shavings); reaching 159% K increase with application of 16 Mg ha^{-1} of the compound in the 0-4 cm depth layer.

P concentration at the beginning of the experiment was below that recommended for the forage species Tifton 85, at approximately 5 mg dm^{-3}; whereas the recommended is above 12 mg dm^{-3} (CQFSRS/SC, 2016), which is good for a soil located at the southwest of Paraná and west of Santa Catarina. However, with the semiannual LSM application, an increase in P concentration was observed in the soil to levels that are considered high. The CQFSRS/SC (2016) considers that P concentration extracted by the $Mehlich^{-1}$ method, as

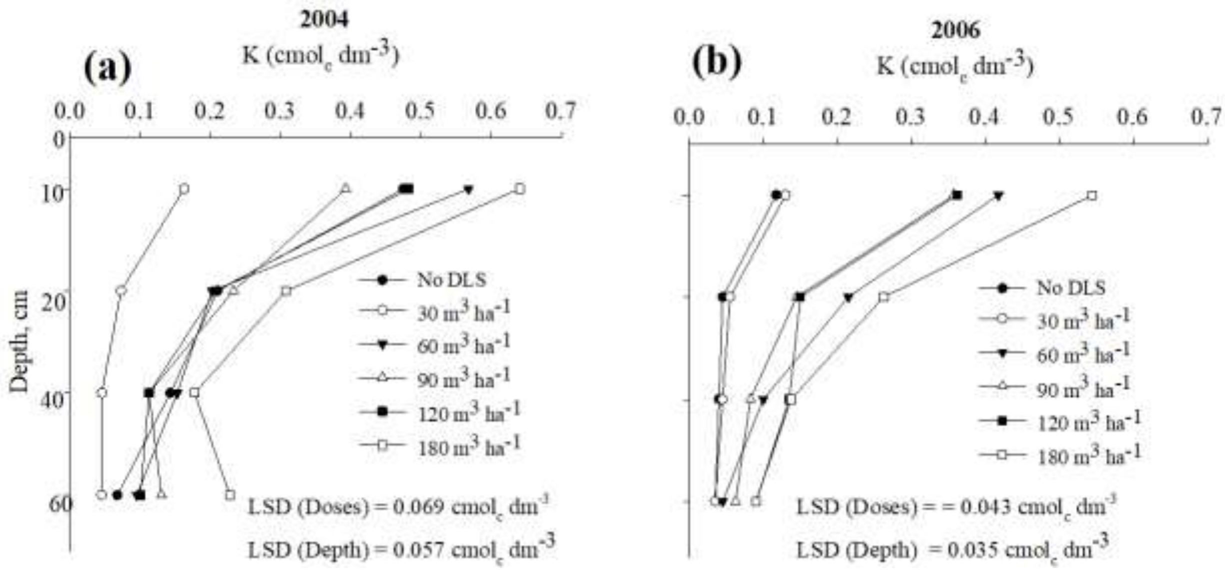

Figure 3. Soil potassium concentration at the depths of 0-10, 10-20, 20-40 and 40-60 cm, as a function of the 0, 30, 60, 90, 120, and 180 m^3 ha^{-1} of LSM application rates. Year 2004 (Figure 3A) and year 2006 (Figure 3B). LSD: Least significant difference.

performed in this study, should not exceed 24 mg dm^{-3} since there is the possibility of fertilizer loss and waste, as well as surface water contamination by phosphates (Berwanger et al., 2008).

Interaction between LSM rates and sample depth was observed for phosphorus concentration in the soil cultivated with Tifton 85 in 2004 and 2006 (Figure 4). The utilization of increasing LSM rates altered P concentration in the soil. Higher concentrations of this element were found when 180 m^3 ha^{-1} LSM was applied. This increment in the concentration, as well as its tendency of higher concentration in the topsoil layer is consistent with results obtained by Ceretta et al. (2003).

There was P accumulation from 2004 to 2006 only in the 0-10 cm layer, for up to 120 m^3 ha^{-1} of LSM use (Figure 4). Under the application of 180 m^3 ha^{-1}, the P concentration also increased at deeper soil layers (0-60 cm). This high LSM rate suggests the possibility of P loss from runoff (Ceretta et al., 2005) since the concentration remained the same between 2004 and 2006. Although higher P concentration was observed at deeper layers, there is evidence of nutrient loss from runoff, which characterizes a rate with potential polluting effect (Menezes et al., 2018).

The accumulation at the topsoil layer was expected, since it presents low mobility in the soil. According to Scherer et al. (1996), approximately two thirds of soil phosphorus is not soluble in water; potentially being part of organic structures and this contributes to the residual effect of manure. Thus, it can be stated that this nutrient stays practically unavailable to plants right after its application, requiring microorganism participation to become available in larger quantities. Phosphorus residual effect in the soil is therefore a consequence of that exposed.

Results published by Berwanger et al. (2008) also point to P increments in deeper soil layers (0-15 cm), attesting nutrient mobility within the soil profile and a contamination risk to subsurface water (Ceretta et al., 2003).

Some studies indicate that 90% of the P applied via LSM might be organic, that is insoluble (Takalson and Leytem, 2009), which contributes to the low leaching of the element in soil profile (Figure 4), under applications that is up to 120 m^3 ha^{-1} and accumulation at the 0-10 cm soil layer. This is not the case for soluble mineral fertilizers which present higher leaching potential of soluble reactive P when compared with organic fertilizers (Bertol et al., 2010). Consequently, LSM stands as an option for fertilization of forage production fields.

The increase in soil fertility, provided by successive LSM applications, led to higher levels of forage production of Tifton 85 in 2003, 2004, 2005 and 2006 (Figure 5), which was observed under higher LSM application rates. In 2003, measured forage production was lower when compared with subsequent years, possibly due to winter and first-year (establishment) carryover effect, even though fertilization responses were already noticeable. Quantification of forage production started in November, 2003.

For 2004, 2005 and 2006, the responses to the organic fertilizer were fitted to positive quadratic models (Figure 5a). There was response to the forage production at 180 m^3 ha^{-1} LSM rate, although $N\text{-}NO_3^-$ concentrations were observed at deeper layers of the soil.

Drumond et al. (2006) observed forage production

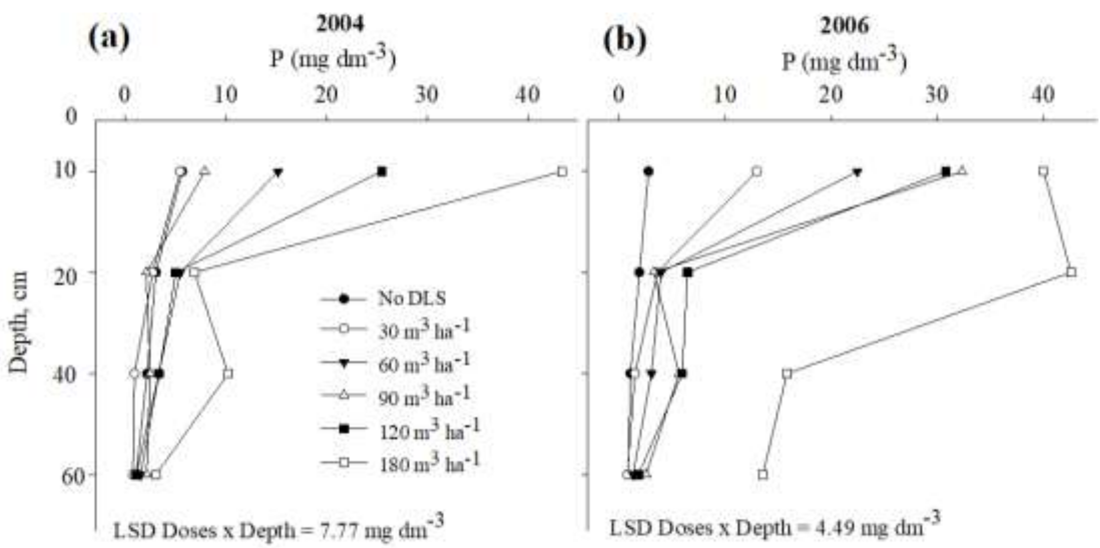

Figure 4. Soil phosphorus concentration at the depths of 0-10, 10-20, 20-40 and 40-60 cm, as a function of 0, 30, 60, 90, 120, and 180 m^3 ha^{-1} of LSM application rates. Year 2004 (Figure 4A) and year 2006 (Figure 4B). LSD: Least significant difference.

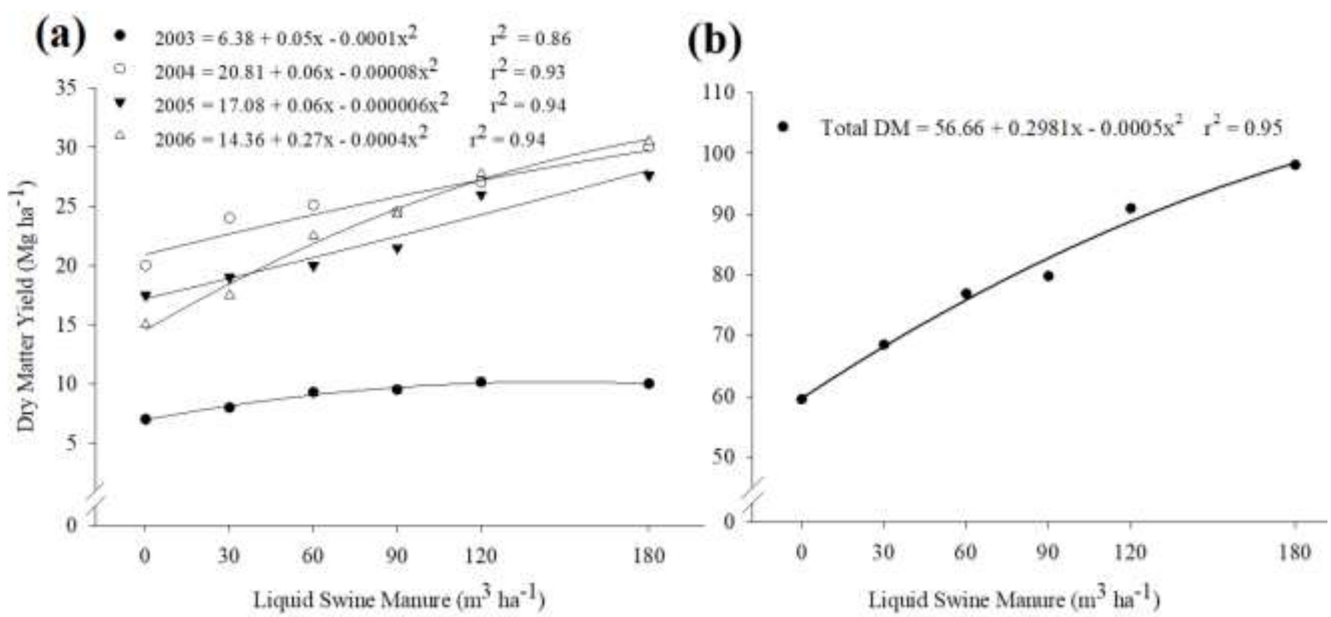

Figure 5. *Cynodon dactylon* cv. Tifton 85 dry matter production as a function of Liquid Swine Manure application rates (0, 30, 60, 90, 120, 180 m^3 ha^{-1}) for the years of 2003, 2004, 2005 and 2006 (Figure 5a) and total accumulated during four years (Figure 5b). IAPAR: Research Station of Pato Branco, 2006.

(Tifton 85) of 5828 DM kg ha^{-1} when 200 m³ of LSM were applied. Their result is not in agreement with the findings of this study, since the LSM application of 180 m^3 ha^{-1} resulted in an annual production of 25000 to 30000 kg ha^{-1} of dry matter between 2004 and 2006 (Figure 5).

Accumulated forage increase with LSM application rates in the four years of study (Figure 5b), portraying the potential of LSM as a fertilizer for perennial forage species, enabling its use as nutrient source to these plants and an option for discard of the manure, which is a concern since it is an environmental contaminant. Given the forage production levels obtained with the application LSM rates of 90 and 120 m^3 ha^{-1}, it is suggested that high quantities should not be used, given the $N\text{-}NO_3$ and P potential for contamination, as shown in this study.

Conclusions

$N-NO_3$ leaching occurs in Tifton 85 pastures when LSM is applied semiannually, at the rate of 90 m^3 ha^{-1}. This rate is suggested as the limit to the use of this fertilizer in respective pasture.

The LSM supplies the nutritional need of Tifton 85 in respect to the availability of N, P and K at a 90 m³ ha^{-1} rate, applied semiannually without causing polluter effect.

Tifton 85 dry matter production responds up to 180 m³ ha^{-1} of LSM application rates. However, the fertilizer utilization efficiency decreases at higher LSM rates, when mineral N, P and K are accumulated in the soil with applications of 120 m³ ha^{-1} of the organic fertilizer presenting an environmental contamination risk.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Aita C, Port O, Giacomini SJ (2006). Dinâmica do nitrogênio no solo e produção de fitomassa por plantas de cobertura no outono/inverno com uso de dejeto líquido de suínos. The Revista Brasileira de Ciência do Solo 30:901-910.

Basso CJ, Ceretta CA, Durigon R, Polett N, Girotto E (2005) Dejeto líquido de suínos: II - perdas de nitrogênio e fósforo por percolação no solo sob plantio direto. Ciência Rural 35:1305-1312.

Berenguer P, Cela S, Santiveri F, Boixader J, Lloveras J (2008) Copper and zinc soil accumulation and plant concentration in irrigated maize fertilized with liquid swine manure. Agronomy Journal 100:1056-1061. doi:10.2134/agronj2007.0321.

Bertol OJ, Fey E, Favaretto N, Lavoranti OJ, Rizzi NE (2010) Mobilidade de P, Cu e Zn em colunas de solo sob sistema de semeadura direta submetido às adubações mineral e orgânica. Revista Brasileira de Ciência do Solo 34:1841-1850.

Berwanger AL, Ceretta CA, Santos DR (2008). Alteração no teor de fósforo no solo com aplicação de dejeto líquido de suínos. Ver Brasileira de Ciências Solo 32:2525-2532.

Bryan NS, Alexander DD, Coughlin JR, Milkowski AL, Boffetta P (2012). Ingested nitrate and nitrite and stomach cancer risk: an updated review. Food and Chemical Toxicology 50:3646-3665.

Ceretta CA, Basso CJ, Pavinatto PS, Trentin EF, Girotto E (2005). Produtividade de grãos de milho, produção de matéria seca e acúmulo de nitrogênio, fósforo e potássio na rotação aveia preta/milho/nabo forrageiro com aplicação de dejeto líquido de suínos. Ciência Rural 35:1287-1295.

Ceretta CA, Durigon R, Basso CJ, Barcellos LAR, Vieira FCB (2003). Características químicas de solo sob aplicação de esterco líquido de suínos em pastagem natural. Pesquisa Agropecuária Brasileira 38:729-735.

Ceretta CA, Lorensini F, Brunetto G, Girotto E, Gatiboni LC, Lourenzi CR, Tiecher TL, De Conti L, Trentin G, Miotto A (2010). Phosphorus fractions in soil after sucessive pig slurry applications in no-tillage system. Pesquisa Agropecuária Brasileira 45:593-602.

Couto RR, Comim JJ, Belli-Filho CRFS, Benedet L, Moraes MP, Bruneto G, Beber CL (2013). Microbiological and chemical attributes of a Hapludalf soil with swine manure fertilization. Pesquisa Agropecuária Brasileira 48:774-782.

CQFS-RS/SC − Comissão de Química e Fertilidade do Solo – RS/SC (2016). Manual de calagem e adubação para os Estados do Rio Grande do Sul e de Santa Catarina. Sociedade Brasileira de Ciência do Solo 376 p.

Domene X, Alcañiz JM, Andrés P (2007). Ecotoxicological of organic wastes using the soil collembolan *Folsomia candida*. Applied Soil Ecology 35:461-472.

Drumond LCD, Zanini JR, Aguiar APA, Rodrigues GP, Fernandes ALT (2006). Produção de Matéria Seca em Pastagem de Tifton 85 Irrigada, com Diferentes Doses de Dejeto Líquido de Suíno. Revista Engenharia Agrícola 26:426-433.

Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA (2013). Centro Nacional de Pesquisa de Solos. Sistema Brasileiro De Classificação De Solos. Embrapa, Brasília.

Franzluebbers AJ, Stuedemann JA (2005). Bermudagrass Management in the Southern Piedmont USA: VII. Soil-Profile Organic Carbon and Total Nitrogen. Soil Science Society of America Journal 69:1455-1462.

Gatiboni LC, Smyth TJ, Schmitt DE, Cassol PC, Oliveira CMB (2015). Soil Phosphorus Thresholds in Evaluating Risk of Environmental Transfer to Surface Waters in Santa Catarina. Revista Brasileira de Ciência do Solo 39:1225-1234.

Lourenzi CR, Scherer EE, Ceretta CA, Tiecher TL, Cancian A, Ferreira PAA, Brunetto G (2016). Atributos químicos de Latossolo após sucessivas aplicações de composto orgânico de dejeto líquido de suínos. Pesquisa Agropecuária Brasileira 51:233-242.

Maak R (1968). Geografia física do Estado do Paraná. Banco de Desenvolvimento do Paraná, Curitiba.

Maccari AP, Baretta D, Paiano D, Leston S, Freitas A, Ramos F, Sousa JP, Klauberg-Filho O (2016). Ecotoxicological effects of pig manure on *Folsomia candida* in subtropical Brazilian soils. Journal of Hazardous Materials 314:113-120.

Menezes JFS, Silva MP, Benett CGS, Benites VM, Cantão VCG (2018) Perdas de água, solo e nutrientes por escoamento superficial após aplicação de dejetos líquidos de suínos na cultura do milho. Revista de Agricultura Neotropical 5:17-22.

Mohedano RA, Costa RHR, Hofmann SM, Belli Filho P (2014). Using full-scale duckweed ponds as the finish stage for swine waste treatment with a focus on organic matter degradation. Water Science and Technology 69:2147-2154.

Mota MR, Sangoi L, Schenatto DE, Giordani W, Boniatti CM, Dall’igna L (2015). Fontes estabilizadas de nitrogênio como alternativa para aumentar o rendimento de grãos e a eficiência de uso do nitrogênio pelo milho. Revista Brasileira de Ciência do Solo 39:512-522.

Nardi VK (2009). Produção de efluente e balanço de nutrientes em granjas de terminação de suínos no oeste do estado do Paraná. 67p. Dissertação (Mestrado) – Programa de PósGraduação em Ciências Veterinárias, Setor de Ciências Agrárias, Universidade Federal do Paraná. Curitiba 2009.

Nikiéma P, Buckley KE, Enns JM, Qiang H, Akinremi OO (2013). Effects of liquid hog manure on soil available nitrogen status, nitrogen leaching losses and wheat yield on a sandy loam soil of western Canada. Canadian Journal of Soil Science 93:573-584.

Oliveira MIL, Becquer T, Goedert WJ, Vilela L, Deleporte P (2011). Concentração de íons na solução de um Latossolo Vermelho sob diferentes sistemas de manejo. Pesquisa Agropecuária Brasileira 46:1291-1300.

Oliveira PAV (1993). Manual de manejo e utilização dos dejetos de suínos. Concórdia: Embrapa Suínos e Aves, Documento, 27. 188 p.

Ourivides OEA, Souza GM, Tiritan CS, Santos DH (2010). Fertilizante orgânico como fonte de fósforo no cultivo inicial de *Brachiaria brizantha* cv. Marandú. Pesquisa Agropecuária Tropical 40:126-132.

Pavan MA, Miyazawa M (1996). Análises químicas de solo: parâmetros para interpretação. Iapar, Londrina 48 p.

Puig P, Soler A, Widory D, Mas-Pla J, Domènech C, Otero N (2017). Characterizing sources and natural attenuation of nitrate contamination in the Baix Ter aquifer system (NE Spain) using a multi-isotope approach. Science of The Total Environment 580:518-532.

Queiroz FM, Mattos AF, Pereira OG, Oliveira RA (2004) Características químicas de solo submetido ao tratamento com esterco líquido de

suínos e cultivado com gramíneas forrageiras. Ciência Rural 34:1487-1492.
Robertson WO (2005). Intoxicação crônica: Metais e outros oligoelementos, in: Goldman L, Ausiello D (ed) Cecil - Tratado de medicina interna. Elsevier Inc, Rio de Janeiro pp. 1280.
Sacomori W, Cassol PC, Ernai PR, Miquelluti DF, Comim JJ, Gatiboni LC (2016). Concentração de nutrientes na solução do subsolo de lavoura fertilizada com dejeto líquido de suínos. Revista de Ciências Agroveterinárias 15:245-258.
Scherer EE, Aita C, Baldissera IT (1996). Avaliação da qualidade do esterco líquido de suínos da região Oeste Catarinense para fins de utilização como fertilizante. Epagri, Florianópolis (EPAGRI. Boletim Tecnico, 79) 46 p.
Scherer EE, Baldissera IT, Nesi CN (2007). Propriedades químicas de um latossolo vermelho sob plantio direto e adubação com esterco de suínos. Revista Brasileira de Ciencia do Solo 31:123-131.
Scherer EE, Nesi NC, Massotti Z (2010). Atributos químicos do solo influenciados por sucessivas aplicações de dejetos suínos em áreas agrícolas de Santa Catarina. Revista Brasileira de Ciencia do Solo 34:1375-1383.
Sharpley AN, Mcdowell RW, Kleinman PTA (2001). Phosphorus loss from land to water: Integrating agricultural and environmental management. Plant Soil 237:287-307.
Takalson DD, Leytem AB (2009). Phosphorus mobility in soil columns treated with dairy manures and commercial fertilizer. Soil Science 174:73-80.
Vielmo H, Bona Filho A, Soares AB, Assmann TS, Adami PF (2011). Effect of fertilization with fluid swine slurry on production and nutritive value of Tifton 85. Revista Brasileira de Zootecnia 40:60-68.
Whitehead DC (1995). Grassland nitrogen. Cab International, Wallingford.
World Reference Base for Soil Resources – WRB (2014). A framework for international classification, correlation and communication. Food and Agriculture Organization of the United Nations. Rome: IUSS/ISRIC/FAO; 2014. World Soil Resources Reports, 106.