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Full Length Research Paper

Different soil tillage systems influence accumulation of soil organic matter in organic agriculture

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As a sustainable method of agriculture, organic agriculture aims to increase the soil organic matter through the use of crop rotation, legume cover crop, animal green manure, and organic compost. These practices add organic residues with high organic Carbon (C) which results in a higher soil organic matter content over time primarily due to the no-tillage practices. However, different soil tillage systems, such as conventional tillage and reduced tillage are also used in organic agriculture, and therefore the accumulation of organic matter does not follow similar trends. The studies under conventional tillage have shown that soil tillage influences negatively the organic matter accumulation in organic agriculture plots, while the results from different studies on organic agriculture showed the potential benefits of reduced or zero tillage for organic matter accumulation.

Key words: Sustainability, soil quality, management systems.

INTRODUCTION

Soil is important to terrestrial ecosystems and represents a balance among physical, chemical, and biological properties. Soil organic matter (SOM) plays a key role in the improvement of these soil properties (Ouedraogo et al., 2007). The increase of SOM is considered critical for sustainable soil management and maintenance of soil productivity (Doran et al., 1996; Fan et al., 2005). In this way, SOM is an important component for the maintenance of sustainable agriculture in the world.

As a sustainable method of agriculture, organic agriculture (OA) aims to increase the SOM through the use of crop rotation, legume cover crop, animal green manure, and organic compost. Usually, these practices add high quantities of organic residues which will be decomposed by soil microorganisms, release nutrients, and increase SOM over time. Globally, OA is regulated

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Table 1. The main characteristics of organic farming systems around the world (adapted from Araújo and Melo, 2010).

S/N	Details
1	Protecting the long term fertility of soils by maintaining organic matter levels
2	Encouraging soil biological activity
3	Nitrogen self-sufficiency through the use of legumes and biological nitrogen fixation, as well as effective recycling of organic materials including crop residues and livestock manures
4	Providing crop nutrients indirectly using relatively insoluble nutrient sources which are made available to the plant by the action of soil micro-organisms
5	Weed, disease and pest control relying primarily on crop rotations, natural predators, diversity, organic manuring, and resistant varieties
6	Careful attention to the impact of the farming system on the wider environment and the conservation of wildlife and natural habitats

by the International Federation of Organic Agriculture Movements (IFOAM). This system occupies 37.5 million hectares worldwide distributed over 164 countries (IFOAM, 2014). Oceania has the largest land area under organic farming (approximately 12.2 million hectares), followed by Europe (approximately 11.2 million hectares), Latin America (approximately 6.8 million hectares), Asia (approximately 3.2 million hectares), and North America (approximately 3 million hectares). In 2012, it was estimated that the land under OA increases by 0.2 million hectares that is, 0.5% globally (IFOAM, 2014).

The practices in OA excludes the use of synthetic fertilizers, pesticides, plant growth regulators, livestock feed additives, and genetically modified organisms. The term 'organic' is best thought of as referring to the concept of the farm as an organism, in which all the component parts - the soil minerals, organic matter, micro-organisms, insects, plants, animals and humans - interact to create a coherent and stable whole. The main characteristics of OA around the world are shown in Table 1. Therefore, OA focuses on alternative agricultural practices using farm-derived renewable resources and biological processes and interactions that will provide an acceptable crop yield (Watson, 2006). Crops under OA require about 50% less energy per unit area; although conventional agriculture may produce more per area, their energy efficiency is lower (Mäder et al., 2002). In this context, an OA system represents an important method that improves soil properties, recycles nutrients, promotes biological process, and increases SOM content (Rigby and Caceres, 2001). High levels of SOM are found to be more closely associated with OA as compared with conventional agriculture (Nardi et al., 2004; Kong et al., 2005; Fließbach et al., 2007; Araújo et al., 2008; Leite et al., 2010; Santos et al., 2012). However, two main points should be considered in global OA systems: the SOM accumulation differs according to the quantity and quality of the C input and the different soil tillage practices significantly affect SOM accumulation over time. Some studies have been shown different trends in SOM accumulation over time (Araújo et al., 2008; Sampaio et al., 2008; Leite et al., 2010; Triberti et al., 2008; Santos et al., 2012, Kong et al., 2005; Fließbach et al., 2007). Therefore, this review focuses on the long-term studies under OA system and its effect on SOM accumulation.

SOM ACCUMULATION IN ORGANIC FARMING SYSTEMS

SOM is a critical component of the soil which affects the physical, chemical, and biological processes of soil and regulates a wide range of soil functions (Leite et al., 2010). The role of SOM in the formation of stable soil aggregates has major implications for soil structure, and consequently, on water infiltration, water holding capacity, aeration, resistance to root growth, and surface crusting (Mirsky et al., 2008). The physical protection of SOM within aggregates is an important factor that controls the dynamics and decomposition of organic C. Aggregate disruption is one of the mechanisms proposed for lower SOM in soil tillage system rather than in no-tillage systems (Six et al., 2000; Leite et al., 2003) because tillage disrupts soil aggregates mechanically, thereby increasing the access of microorganisms to SOM (Jiao et al., 2006). SOM is considered as a source of soil cation exchange capacity (CEC) by which the cations are

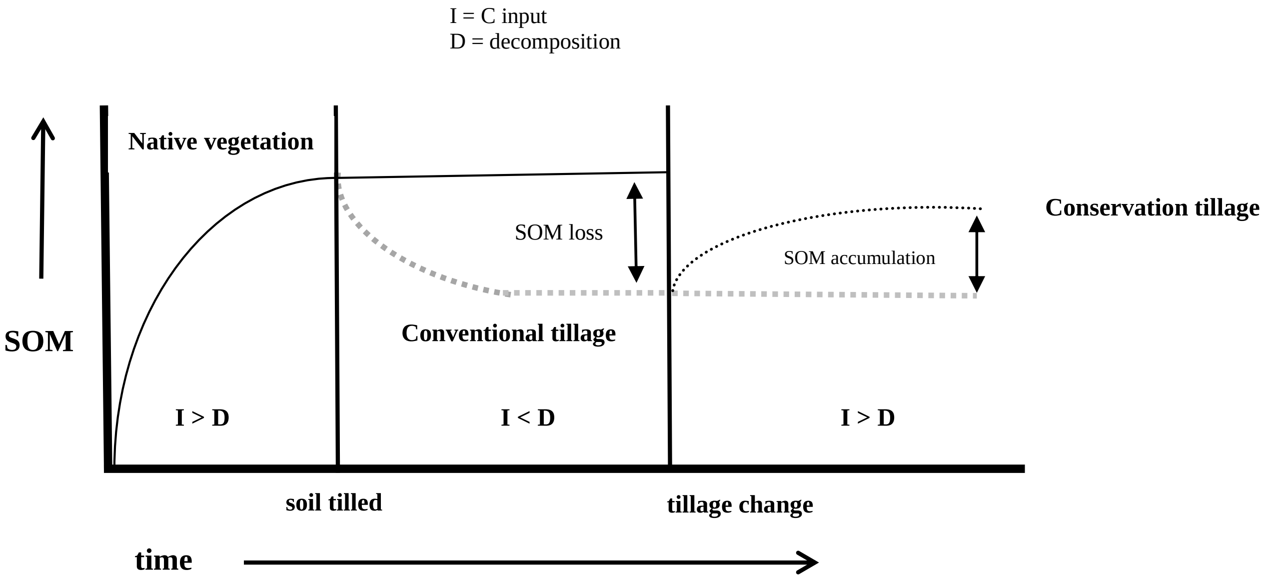

Figure 1. Trend in soil organic matter accumulation from conventional tillage and conservation tillage as compared with native soil.

retained for plant use and can be readily exchanged for other cations. The exchange is quite often made is the intake of a hydrogen ion from plant roots, which replaces one of the cations in the exchange complex. By reducing fixation and leaching losses of the cations, the CEC helps maintain a more constant nutrient supply and potentially increases crop yields (Craswell and Lefroy, 2001; Bot and Benites, 2005). SOM has an intense effect on the number and type of soil organisms. These organisms, consisting of microflora and microfauna, do not just live passively in soil but are affected by one another, either through competition or a symbiotic relationship. They frequently compete with one another for nutrients or energy, much of which is derived from organic matter. Once the organisms have been nourished by organic matter, they may become an energy and nutrient source for other organisms. Most soil organism activities are beneficial to crop plants. In fact, soil fertility is related to the number and diversity of the organisms it can support (Wolf and Snyder, 2003).

More recently, SOM has attracted great interest because of the phenomenon of global warming and the prospects of using soil as a reservoir of carbon released to the atmosphere (CO_2) by human activities. The best strategies to build-up carbon stocks in the soil are basically those that increase the crop residue addition to the soil or decrease the SOM decomposition rate (Lal, 2004). In fact, soil organic carbon (SOC) storage is a balance between C additions from non-harvested portions of crops and organic amendments and C losses. The losses are primarily from organic matter decomposition and the release of respired CO_2 to the atmosphere and, to a lesser extent, by the erosion and leaching of dissolved organic carbon (Kemmit et al., 2008). Organic matter returned to the soil directly from crop residues or indirectly as manure consists of many different organic compounds. The result is a quick formation of microbial compounds and body structures, which are essential for holding particles together to provide structure to the soil and release CO_2 back to the atmosphere through microbial respiration (Liu et al., 2006).

Organic C is a major component in OA systems and has a positive effect on soil C because a significant increase in SOM is correlated with C input (Drinkwater et al., 1998). The input of residues with high organic C results in a higher SOM content over the long-term. Several studies on OA have demonstrated this increase in the SOM content (Araújo et al., 2008; Sampaio et al., 2008; Leite et al., 2010; Triberti et al., 2008; Santos et al., 2012, Kong et al., 2005; Fließbach et al., 2007). The conversion from native soil to agricultural systems, through soil tillage practices, decreases the SOM content in the soil (Rees et al., 2001). It happens because conventional practices, such as soil tillage, stimulate the degradation of SOM, compared to native vegetation, and do not allow organic C to accumulate in soil (Figure 1). The use of soil tillage promotes a strong decline in SOM during the transition from native vegetation to cropland. Thus, selecting a conservation soil tillage may be important for minimizing negative tillage effects on SOM and, therefore, the adoption of conservation tillage tends

Table 2. Main characteristics of long-term organic farming studies.

Crop	Soil amendment	Soil management	Soil type	Reference
Acerola" fruit (Malpighia glabra)	Composted cow manure, rock phosphate, and straw	Zero tillage	Typic Quartzipsamment	Santos et al. (2012)
Maize/bean	Organic compost and straw	No-tillage	Typic Hapludult	Leite et al. (2010)
Tomato, maize	Legume cover crop, chicken and turkey manure, organic compost	Conventional tillage	Typic Xerorthent	Kong et al. (2005)
Maize	Manure and legume cover crop	Conventional tillage	-	Hepperly et al. (2006)
Maize, soybean, potato	Animal manure, compost, turkey litter	Conventional tillage	Typic Udipsamment	Tu et al. (2006)
Potato, wheat	Famyard manure, slurry and organic compost	Conventional tillage	Typic Hapludalf	Fließbach et al. (2007)
Potato, wheat	Cow manure, slurry	Reduced tillage	Eutric Cambisol	Berner et al. (2008)
Cereal, sunflower	Manure compost, slurry	Conventional tillage, Reduced tillage	Eutric Cambisol	Gardemeier et al. (2011)
Maize, wheat	manure, slurry, maize residues	Conventional tillage	Haplic Calcisol	Triberti et al. 2008

to accumulate SOM in long-term.

SOIL TILLAGE SYSTEMS

Soil tillage systems are practices of soil manipulation aiming to improve conditions for germination, seedling establishment and crop growth (Lal and Kimble, 1997). These practices vary in different ways and frequency affecting the biological, physical and chemical properties of the soil (Mathew et al., 2012). Usually, conventional soil tillage practices are used in several agricultural systems and may adversely affect long-term soil productivity due to erosion and loss of organic matter in soils (Leite et al., 2009). These systems generally involve plowing or some other form of intensive tillage. However, conservation soil tillage is defined as a tillage system in which at least 30% of crop residues are left in the field and is an important conservation practice to reduce soil erosion (Uri, 1999). As a specialized type of conservation soil tillage, the no-tillage system consists of a one-pass planting and fertilizer operation in which the soil and the surface residues are minimally disturbed (Šimon et al., 2009). Additionally, zero tillage system has been shown to improve or to maintain organic matter in soil due to reduced soil disturbance (Mangalassery et al., 2015).

Conservation soil tillage are recognized as useful agricultural practices for sustainable agriculture and food system because of the economic, environmental, sustainable benefits (Mangalassery et al., 2015). The positive agricultural practices, such as very little or no soil disturbance, direct drilling into untilled soil, crop rotation, and permanent soil cover, maintain and improve soil properties (Holland 2004; Derpsch 2007). Also, conservation soil tillage practices change many soil properties when implemented for a long term (Chen et al., 2009).

Conservation soil tillage may be characterized by increased SOM due to surface residue accumulation in soil and this permanent increase in SOM in the top soil improves the availability of plant nutrients (Fernández et al., 2007; Lopez-Fando and Pardo, 2009), which are released faster than in conventional tillage (Fernández et al. 2007). Therefore, conservation soil tillage systems affect the accumulation of SOM and the increases in organic matter are normally observed within the surface 10 cm of soil (West and Post, 2002). Also, soil under conservation soil tillage system accumulates greater amounts of total C and a greater proportion of aromatic C (Mangalassery et al., 2015). However, many studies indicate that various soil tillage systems have a strong effect on SOM accumulation and the effects varied depending on regional climate, soil type, residue management practice, and crop rotation (Koch and Stockfisc, 2006; Leite et al., 2009; Šimon et al., 2009; Chen et al., 2009; Mathew et al., 2012; Abdullah, 2014; Mangalassery et al., 2015).

EFFECT OF DIFFERENT SOIL TILLAGE ON SOM ACUMULATION

Conventional and conservation are both used in OA systems (Table 2), and therefore, the accumulation of SOM does not follow similar trends (Table 3). In OA systems, tillage is used to ploughing the soil between crops in order to

Table 3. Organic C input and SOM accumulation in organic farming system over time.

Period (years)	C input (Mg ha^{-1})	SOM accumulation (mg kg^{-1})	Reference
10	8,000	25.6 (+310%)	Santos et al. (2012)
12	8,400	36.2 (+40%)	Leite et al. (2010)
15	6,000	23.6 (+30%)	Kong et al. (2005)
5	10,200	19.2 (+20%)	Tu et al. (2006)
18	5,000	26.5 (-13%)	Fließbach et al. (2007)
7	6,000	40.2 (+14%)	Berner et al. (2008)
6	5,500	44.7 (+19%)	Gardemeier et al. (2011)
34	2,100	11.6 (-12%)	Triberti et al. (2008)

incorporate crop residues and soil amendments, remove weed growth, and prepare a seedbed for planting. In 1978, a long-term study under OA was started comparing organic and conventional agriculture in Switzerland (Fließbach et al., 2007). The main practices used in OA plots are crop rotation (potatoes, wheat, and beetroots, followed by three years of grass-clover), manure, and soil tillage. After 21 years, SOM was found to decrease by 13% and 8% at low intensity and high intensity tillage areas under OA, respectively. According to Fließbach et al. (2007), the organic practices follow a guideline in Switzerland that comprise a variety of management steps, including tillage of soil, thus SOM may fluctuate according to the long-term land use.

The results reported by Fließbach et al. (2007) confirmed that soil tillage influenced SOM accumulation in OA plots. Similarly, a field study, which was a long-term research on agriculturalsustainability at the University of California, Davis, USA, compared a conventional and an organic maize–tomato crop system with legume cover crop, compost and no pesticides (Kong et al., 2005) that had been under standard soil tillage since 1993. After 15 years, the SOM accumulation results showed a marginal increase in the SOM content in OA system over time. The same trend was found in another experiment that had been maintained under organic farming practices since 1981. The Rodale farming system, followed in some parts of Pennsylvania, USA, evaluated OA on the basis of manure and legume coverage required by the crop under conventional tillage. In that system, Hepperly et al. (2006) observed that SOM accumulation increased by 14% under OA over a 20 year period.

In southeastern Italy, a long-term field experiment (1966 to 2000) compared rotational application of organic and mineral fertilizations performed over duration of 2 years under conventional soil tillage: maize and winter wheat with cattle manure, cattle slurry and wheat or corn residues together with an unfertilized control (Triberti et al., 2008). The authors observed that in the year 2000, the SOM content was 12% lower than that in 1966. Thirty-four years after the commencement of the trial, the organic amendment revealed no significant effects on SOM accumulation. According to the authors, plowing the soil caused a dilution of SOM and promoted oxidation, and the adoption of deep soil tillage in an intensive cereal succession caused the decrease in SOM.

Soil tillage is an important factor that influences SOM accumulation because tillage exposes more soil to oxygen and increases the breakdown of organic matter by microorganisms. Although soil tillage may increase soil microbial biomass and its activity (Gadermaier et al., 2011), the SOM accumulation in tilled soils may decrease over time. Although tillage is a very common practice and is recommended for OA mainly to control weeds, suitable crop rotations with a high weed-suppressing capacity may be an alternative to tillage. The use of reduced tillage in organic farming has not yet been successfully implemented and the development of suitable crop rotations and management practices that promote weed control should be investigated to avoid tillage (Peigné et al., 2007). Reduced tillage appears to correlate with an increase in SOM (Gadermeier et al., 2011). For example, Gadermeier et al. (2011) evaluated an OA system from 2002 to 2008 that operated under reduced tillage and found a 19% increase in the SOM. Emmerling (2007) observed a 10% increase in SOM under reduced tillage after 10 years of OA and no differences under tilled soil. Berner et al. (2008) evaluated the effects of reduced soil tillage on SOM accumulation over seven years and found a 14% increase in SOM.

Another option is zero soil tillage which refers to direct seeding and direct drilling with no soil disturbance. Zero soil tillage is the conservation tillage system which may accumulate high amounts of organic residue on the soil surface, and the benefits are most pronounced in dry regions (Car et al., 2013). When the soil is not tilled, SOM accumulation seems to be higher and it favors a fast increase in the SOM content. Organic agriculture without tillage may reduce energy use and CO_2 emissions while increasing C sequestration (Holland, 2004) and system sustainability (Davies and Finney, 2002).

Under no-tillage or zero tillage systems, OA has significantly higher SOM accumulation (Leite et al., 2010; Araújo et al., 2008; Wang et al., 2011; Santos et al., 2012). Leite et al. (2010) evaluated the SOM changes over a long-term (12 years) addition of organic compost under an OA system of a maize/bean intercrop under no-tillage in Brazil. The authors observed that SOM values were approximately 40% higher in the no-tilled organic farming system compared with a conventional system. The magnitude of increase was not high; however, the application of organic compost associated with the no-tillage system favored the accumulation of SOM over time. Compost application has been evaluated with other practices, which can increase the SOM content, such as cover crop, crop rotation, and no-tillage. In Brazilian semi-arid areas, Menezes and Silva (2008) evaluated entisol soil and the effects of compost application (15 t ha^{-1}) and/or a cover crop (rattlepods, *Crotalaria juncea*) on the SOM content over a six-year period. The annual fertilization with compost, with or without *C. juncea,* increased the SOM content.

No-tillage practices in organic farming from tropical or sub-tropical regions is as important practice to avoid high organic matter decomposition as in humid and warm regions there is highest soil microbial activity which is stimulated by tillage practices. The long-term experiment with OA in the USA evaluated during 15 years the cumulative effects of agricultural practices on accumulation of SOC (Wang et al., 2011). The study was established in 1994 comparing tillage and no-tillage practices with chemical or organic inputs. The results showed that the total organic C content was significantly higher (77–83%) in no-tillage than in tillage systems. Also, soil organic C was 44% higher in no-tillage organically managed compared to no-tillage with chemical inputs. Therefore, Wang et al. (2011) showed that OA with no-tillage practices and organic inputs can promote soil C accumulation over time.

In a study of the effects of 40 years of farmyard manure, mineral and mixed fertilizations on the organic properties of a fluvi-calcaric cambisol soil from northeastern Italy, Nardi et al. (2004) also reported a larger influence of the organic practices on the SOM content. A study on OA in sandy soil with fruit production and under no tillage management showed a SOM accumulation > 300% over 10 years (Santos et al., 2012). This SOM accumulation is important because sandy soils present low fertility and the increase in SOM may improve soil properties. Comparing the aforementioned three studies, we found that soil tillage influenced SOM accumulation and the quantity and quality of the C input affected SOM accumulation over time.

Recently, Alvaro-Fuentes et al., (2013) evaluated the long-term effects of different tillage systems on soil organic C levels in the 0 to 50 cm soil layer under dryland semiarid conditions in Spain. The experiment compared three tillage systems: two conservation tillage systems (no-tillage and reduced tillage) and one intensive tillage system (conventional tillage). The highest soil organic C contents were found in the no-tillage system. However, the differences only were found in the soil layer submitted to tillage. It means that the effect of tillage on accumulation of soil organic matter may be restricted to the plough layer.

CONCLUSION

Different soil tillage systems affect strongly the SOM accumulation in organic agriculture. The results from different studies on organic agriculture showed the potential benefits of reduced or zero tillage for SOM accumulation over time. Finally, this higher accumulation of soil organic C found in conservation soil tillage systems may increase soil fertility and can contribute to alleviate atmospheric CO_2 rise.

Conflict of interests

The authors have not declared any conflict of interests.

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Irrigation depth and harvest date in sweet potato for conversion to biofuels

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This study aimed to evaluate the effect of different irrigation depths and harvest dates in sweet potato for conversion to biofuels. Irrigation treatments were 0.25, 0.50, 0.75, and 1.0 of crop evapotranspiration rates and a control treatment (without irrigation). Harvest dates were: 90, 120, 150, 180, and 210 days after planting (DAP). The sweet potato cultivar BRS Cuia (RNC-27.315) was utilized. The experimental design was a randomized block in factorial arrangement (irrigation depths combined with harvest dates) with four replications. Reference crop evaporation was calculated based on the method of FAO Penman-Monteith. Drip irrigation system was used and irrigation frequency was every seven days. The highest and lowest yield were at 90 and 210 DAP, respectively. The lowest yield variation was between 120 and 150 DAP. Control treatment had highest yield in all harvest dates. Efficient water use was greater with irrigation of 0.25 of ETc with 116.9 and 218.8 m^3 ha at 90 and 210 DAP, respectively. Starch content, crude protein, length and diameter of the root, and yield were influenced by different irrigation depths and harvest dates.

Key words: *Ipomoea batatas,* irrigation management, ethanol feedstock, drip irrigation, water deficit, efficient irrigation strategies.

INTRODUCTION

Sweet potato (*Ipomoea batatas*) had an average yield of 9.13 t ha^{-1} in a planted area of 500,350 ha, during 2013 in Brazil. The southern region is the main producer, accounting for 45% of production with 227,354 t. The state of Rio Grande do Sul produced 166,354 t, with an average productivity of 13.42 t ha^{-1}, which represents 73.9% of the southern region and 32.9% of the whole country production (IBGE, 2013). In 2009, world production was 102.7 million t cultivated in an area of 8.0 million ha, which provide an average yield of 12.8 t ha^{-1} (FAO, 2012). China is the largest producer, with a total production of 3.7 million t and an average yield of 23.1 t

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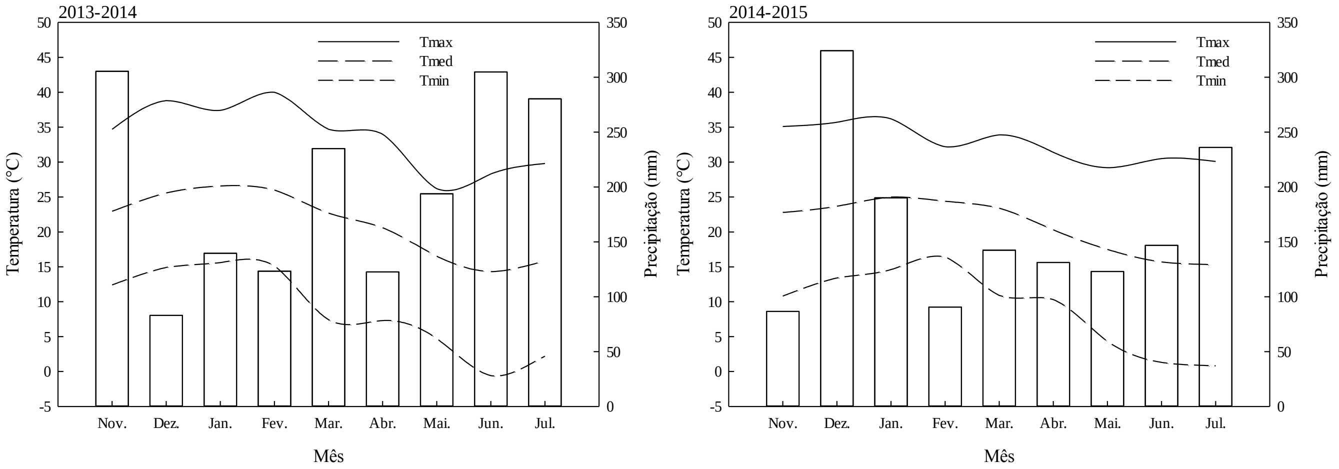

Figure 1. Climograph of experimental area during the 2013-2014 and 2014-2015 periods.

ha^{-1} (FAO, 2010).

Searching for new raw materials produced from biomass for production of clean and renewable fuels has received great attention. The ethanol production has become an international priority, which will redefine a new geopolitical position due to the entry of countries in the biofuel production route (Silveira et al., 2008; Santana et al., 2013). According to Souza (2005), the ethanol production from starch has been studied in countries holding high technology, such as Germany, Belgium, Denmark, United States, Canada, and China. Among other reasons, sweet potato has great biomass yield to obtain ethanol, associated with planting hardiness and two annual harvests. The ethanol derived from sweet potato is very competitive in terms of yields in comparison with sugarcane, with a production of 170 L t^{-1}, compared with only 80 L t^{-1} from the sugarcane ethanol (Silveira, 2008). The crop can be an alternative to the ethanol plants and farmers during the growing season after the sugarcane planting (Pavlak et al., 2011).

The water resources for agriculture are declining and the population continues to grow. Proper management and irrigation water quality have fundamental importance for achieving high yield, quality, cost reduction, and rational water use (Padrón et al., 2015a).

Regarding the need of raw materials diversification for the production of biofuels, sweet potato appears as an alternative for having a high starch production potential. Moreover, this crop can be used in the sugarcane off-season and also in regions where the weather conditions are not adequate for sugarcane planting. In this context, this study aimed to evaluate the effect of different irrigation depths and harvest dates in sweet potato for conversion to biofuels in Santa Maria-RS, Brazil.

MATERIALS AND METHODS

The experiment was carried out in a field at the experimental area of the Polytechnic School of the Federal University of Santa Maria, Rio Grande do Sul (RS), Brazil, located at 29°41’25”S, 53º48’42"W, and altitude of 110 m, during the periods of 2013-2014 and 2014-2015. The predominant soil in the region is Paleudalf and shows a frank texture, according to Soil Taxonomy (USDA, 1999). According to the Köppen-Geiger climate classification, the climate of the region is humid subtropical (Cfa). Rainfall, minimum, average, and maximum temperature are shown in Figure 1. Among 2013-2014 and 2014-2015 periods, the minimum, average, and maximum temperature ranged from 13.8, 16.2, 12.3 and 7.0; 15.6 and 9.6°C, respectively, showing greater variation in the first period. The maximum rainfall obtained in the 2013-2014 period was in June and during 2014-2015 period in January, and the minimum rainfall was in December in both periods.

The experimental design was a randomized block in a factorial design with four replications, where the factors were the irrigation depths and harvest dates. The treatments consisted of applying supplementary irrigation depths: 0.25, 0.50, 0.75, and 1.0 of reference evapotranspiration and a control treatment (without irrigation). The harvest dates were: 90, 120, 150, 180, and 210 Days after Planting (DAP). The experimental unit consisted of 20 m^2 (4x5 m), and 400 m^2 of total experimental area, without plants on the border. The sweet potato cultivar used was BRS Cuia variety (RNC-27,315), which is commonly utilized in the region and launched by EMBRAPA in 2011 as a variety developed for the State of Rio Grande do Sul (Castro et al., 2011). Planting was carried out in December 2013 and November 2014, with spacing of 1 m between rows and 0.4 m between plants, totaling 1,000 plants and plant density of 2.5 m^{-2}.

Localized drip irrigation was used with spacing of 0.20 m between drippers and flow of 0.8 L h^{-1}. One spherical gate to regulate the irrigation times and one pressure control valve to obtain regular pressure were installed in each experimental unit. The irrigation strategy consisted of keeping soil moisture at field capacity from planting to 20 DAP, ensuring the establishment of seedlings. Irrigation treatments were applied after the initial phenological stage (20 DAP) with irrigation frequency of every seven days and irrigation continued until 90 DAP.

The reference evapotranspiration (ETo) was calculated based on the methodology of Penman-Monteith/FAO (Equation 1), and the crop evapotranspiration (ETc) at a standard condition was based on Equation 2 (Allen et al., 2006). Climate data were obtained from the weather station of the Federal University of Santa Maria, linked to the National Institute of Meteorology, localized approximately 2000 m from the experimental area. Rainfall (mm), maximum and

Table 1. Soil attributes of the experimental area.

Soil layers	pH	Ca	Mg	Al	(H+Al)	CEC efet.	Saturation (%)		Index	OM	S	P-Mehlich
(m)	water	-------------cmol$_c$ dm^{-3}-----------					Al	Base	SMP	(%)	----mg dm^{-3}----	
0-0.2	5.8	9.7	3.5	0.2	3.9	13.8	1.6	76.1	6.2	3.3	11.0	14.2
0.2-0.3	5.2	8.5	2.4	0.8	6.6	12.0	7.9	63.4	5.8	2.5	7.1	11.5

	Bulk density (g cm^{-3})	Field capacity (m^3 m^{-3})	Infiltration (mm h^{-1})	Texture
0-0.2	1.42	0.31	15.0	Loam
0.2-0.3	1.38	0.34		Clay-loam

Table 2. Evapotranspiration, irrigation depth, and number of irrigations in the experimental periods.

Treatment	Period 2013-2014						
	ETc (mm)					Irrigation depth (mm)	Number of irrigations (days)
	Days after planting						
	90	120	150	180	210		
$T_{0.25}$	107.1	129.4	140.6	147.4	154.4	83.9	14
$T_{0.50}$	214.3	258.9	281.2	294.8	308.9	167.9	
$T_{0.75}$	321.4	388.3	421.8	442.2	463.3	251.8	
$T_{1.0}$	428.5	517.7	562.4	589.6	617.8	335.7	
	Period 2014-2015						
$T_{0.25}$	99.0	127.8	144.9	156.8	164.5	68.3	16
$T_{0.50}$	198.0	255.5	289.8	313.6	328.9	136.6	
$T_{0.75}$	297.0	383.3	434.6	470.4	493.4	204.8	
$T_{1.0}$	396.0	511.0	579.5	627.2	657.9	273.1	

minimum temperature (ºC), maximum and minimum relative air humidity (%), insolation (hours), and wind speed (m s^{-1}) were collected daily.

$$\mathrm{ETo} = \frac{0.408\,\Delta\,(Rn - G) + \gamma \frac{900}{\mathrm{T} + 273} U_2 . (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)} \qquad (1)$$

$$\mathrm{ETc} = \mathrm{kc} \times \mathrm{ETo} \qquad (2)$$

Where ETo is the reference evapotranspiration (mm day^{-1}), Rn is net radiation value at crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), and T is daily mean air temperature at 2 m height (°C). Also, U_2 , es, ea, Δ, and γ represent wind speed at two meters height (m s^{-1}), saturation vapor pressure (kPa), actual vapor pressure (kPa), slope of the saturation vapor pressure curve (kPa °C^{-1}), and psychrometric constant (kPa °C^{-1}), respectively. Conversion factor for the term (Rn-G) of (MJ m^{-2} dia^{-1}) to (mm dia^{-1}) was 0.408. Moreover, ETc stands for crop evapotranspiration (mm) and kc is the single crop coefficient. The chemical analysis of soil was determined in soil laboratory of Rural Science Center (UFSM). Bulk density, field capacity and infiltration test were performed in field as reported in (Padrón et al., 2015b) (Table 1).

Root mass yield was evaluated in ten plants per plot in each harvest. Also, the length and diameter of the root were evaluated in each harvest, using digital caliper. For root development comparison in each crop, the roots were ranked in commercial production (200 g to 500 g) and industrial production (less than 200 g and greater than 500 g). The chemical analysis of the root: starch and protein, content were evaluated in three plants in each harvest, obtaining a composed sample. The samples were evaluated in the Pisciculture Laboratory of UFSM, using the method of AOAC 996.11 adapted by (Walter et al., 2005). Furthermore, the Water productivity (WP), with total yield (kg ha^{-1}) divided by evapotranspiration (mm) (Equation 3) and irrigation water productivity (IWP), with the fresh total yield (kg ha-1) divided by total irrigation water applied (Equation 4) (Padrón et al., 2015c).

$$\mathrm{WP} = \frac{\mathrm{Total\ yield\ (kg\ ha^{-1})}}{\mathrm{Evapotranspiration\ (mm)}} \qquad (3)$$

IWP = Total yield (kg ha-1) / Irrigation water applied (mm) (4)

The main tasks of agronomic management were: applied 3.5 t ha^{-1} of dolomitic lime to correct pH, distributed to haul and embedded with grid, fertilization (47.5 kg ha^{-1} of urea, 225 kg ha^{-1} of triple superphosphate 42% P, and 262.5 kg ha^{-1} of potassium chloride), these applications were in accordance with the chemical analysis of soil. Also was performed, weed control, and spraying of insecticide and fungicide. Statistical analysis was performed using SPSS® software, version 20. Comparison of means was performed by Tukey test at 5% probability. Data were clustered if not presented interactions among the years.

RESULTS AND DISCUSSION

The evapotranspiration, number of irrigations, and applied irrigation for the periods of the experiment are presented in Table 2. Comparing the periods of trials, the

Table 3. Accumulated rainfall (mm) in the experimental period.

Period	Days after planting				
	90	120	150	180	210
2013-2014	302.8	582.2	696.6	866.2	1,234.0
2014-2015	565.8	681.0	862.6	930.4	1,057.8

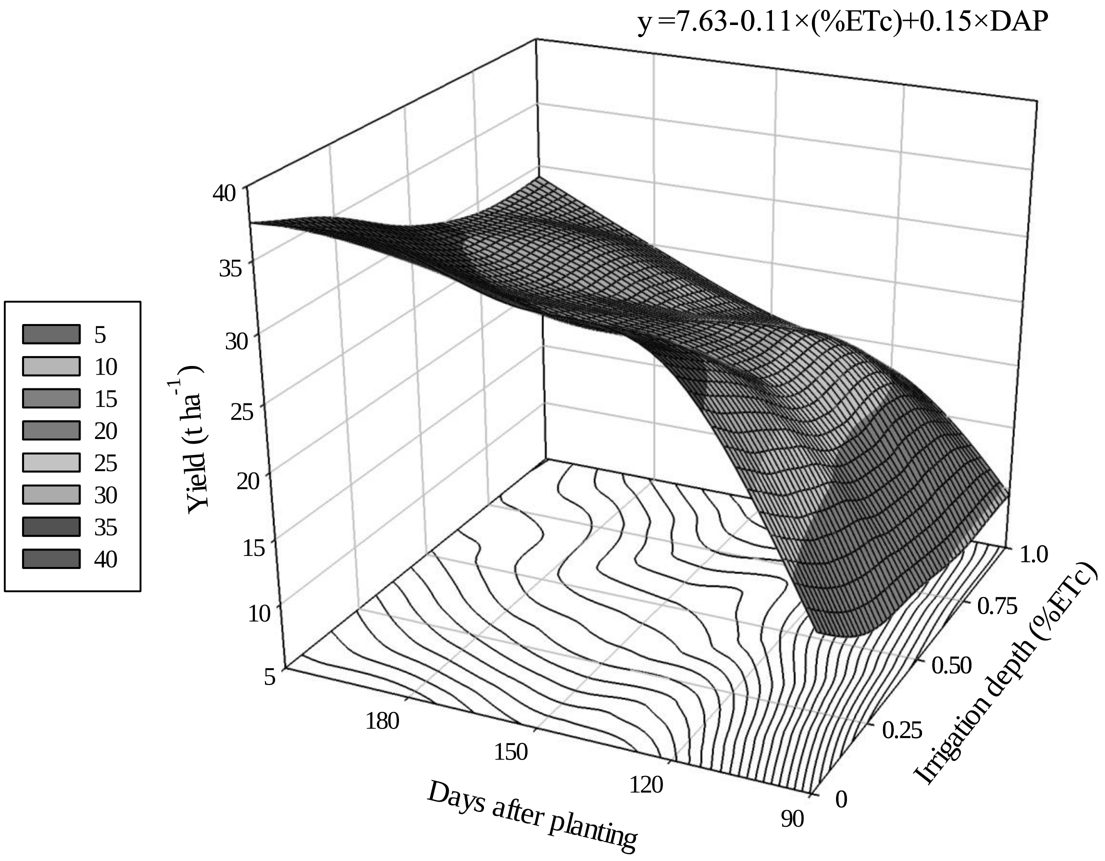

Figure 2. Yield response surface of sweet potato according to the harvest dates and irrigation depths.

difference of irrigation depth of 100% ETc was 62.6 mm and 2 days in the number of irrigations. The period of 2013-2014 showed a lower number of irrigation days but greater irrigation depth applied compared to the 2014-2015 period. It can be inferred that this difference occurred due to weather conditions, temperature, and rainfall. The maximum cumulative evapotranspiration was higher in the 2014-2015 period, showing a difference of 40.1 mm, being different in the first two harvests at 90 and 120 days after planting (DAP). Nogueira et al. (2015) determined the evapotranspiration and irrigation depth for sweet potato with 125 DAP in locality of Santa Maria-RS during a period of 20 years, obtaining an average of 562.2 mm and 266.6 mm, respectively.

The accumulated rainfall at each harvest date are shown in Table 3. The greater cumulative rainfall was in the 2013-2014 period. The greater variation was from 180 to 210 DAP, with 367.8 mm and between 90 and 120 DAP, with 279.4 mm. The 2014-2015 period the greater variation was of 127.4 mm from 180 to 210 DAP and between 90 and 120 DAP, with 115.2 mm.

Yield in terms of harvest dates and irrigation depths are shown in Figure 2. Statistical analysis showed interaction among irrigation depths and harvest dates. The lowest yield was at 90 DAP and showed a statistically significant difference at the level of 5% probability between treatments. The yield increased during the period of 90 to 210 DAP in 21, 23, 20, 20, and 20 t ha^{-1}; from 120 to 210 DAP in 5, 7, 8, 6, and 11 t ha^{-1}; from 150 to 210 DAP in 3, 5, 4, 5, and 8 t ha^{-1} at T_0, $T_{0.25}$, $T_{0.50}$, $T_{0.75}$, and $T_{1.0}$, respectively, with the greater variation during the periods described in $T_{0.25}$, $T_{1.0}$ e $T_{1.0}$, respectively. The 210 DAP

Table 4. Water productivity and irrigation water productivity of sweet potato as a function of the harvest dates and irrigation depths.

Treatment	Water productivity(*) and irrigation water productivity (kg m^{-3})				
	Days after planting				
	90	120	150	180	210
T_0(*)	40.6	63.0	61.0	61.8	58.9
$T_{0.25}$	116.9	218.7	210.0	209.3	218.8
$T_{0.50}$	52.5	92.0	95.4	93.3	97.9
$T_{0.75}$	30.9	59.7	55.9	60.8	61.0
$T_{1.0}$	22.9	35.2	36.5	40.7	45.7

period showed greater yield, even when the period of 120 to 150 DAP was the period which demonstrated the lowest variation in reference to 210 DAP. It can be inferred that for this variety and these study conditions, the optimal harvest date was between 120 and 150 DAP, agreeing with Castro et al. (2011), which commented that the harvest period for variety BRS Cuia is between 120 and 140 DAP, with planting from August for this region.

In all harvests, the highest yield was at T_0 and the smallest in $T_{1.0}$. With this climatic conditions and soil characteristics (moisture retention and texture), irrigation influenced the crop yield during the study period. However, irrigation is necessary in prolonged periods of dry weather. Also, greater vegetative development was observed in treatments under irrigation in comparison to T_0. In the study area, Erpen et al. (2013) used the sweet potato variety Princess and recommended supplementary irrigation only after long periods without rainfall of 10 to 15 days. Mantovani et al. (2013) studied different water depths (50, 75, 100, and 125% of ETc) in two fresh potato cultivars (Amanda and Duda) and they concluded that increasing water depth resulted in increased yield of tuberous roots of both cultivars. However, this increase was not linear, reaching a maximum yield of 49.8 t ha^{-1} with application of 325.5 mm for Amanda cultivar and 67.1 t ha^{-1} with the application of 347.0 mm for Duda. Moreover, the maximum efficiency in the water use for sweet potato cultivars was reported as 237 and 146 m^3 ha^{-1}, for Amanda and Duda, respectively. Also, Júnior et al. (2009) studied the same sweet potato cultivars (Amanda and Duda) in rainfed condition and they found productivities ranging from 22.0 to 45.4 t ha^{-1}. Cardoso et al. (2005) evaluated traits of tuberous roots of 16 sweet potato clones and they observed maximum yield of 28.5 t ha^{-1}, fresh matter of 14.1 t ha^{-1}, and commercial root yield of 21.3 t ha^{-1}. Queiroga et al. (2007) assessed the physiology and production of sweet potato cultivars in function of harvest date and they obtained the highest total yield values (20.7 t ha^{-1}) and commercial roots (17.7 t ha^{-1}) at 155 DAP. Miranda (2006) evaluated sweet potato clones and obtained root yield of 25 t ha^{-1} with the Brazlândia Roxa cultivar and 33 t ha^{-1} with the Brazlândia Rosada cultivar at 150 DAP. In Porteirinha-MG, Resende (1999) assessed eight sweet potato cultivars and recorded average commercial roots yield of 17.5 and 10.8 t ha^{-1} in conditions of supplementary irrigation and rainfed, respectively. Also, in the northern region of Minas Gerais, Resende (1999) studied sweet potato cultivars under irrigated conditions and rainfed. The Brazlândia Branca cultivar stood out for its commercial yield (22.3 t ha^{-1}), followed by the cultivars Paulistinha (21.3 t ha^{-1}) and Princesa (19.0 t ha^{-1}), which showed no significant differences among themselves. Moreover, the lowest yield was obtained by the cultivar Brazlândia Roxa (13.5 t ha^{-1}), which showed no significant differences with the cultivars Coquinho, Rama Roxa, Arroba, and Brazlândia Rosada. Probably, the low yield occurred in the period of 150 DAP because it is considered insufficient for its full vegetative growth, resulting in greater-yielding of scrap roots (7.2 t ha^{-1}), and roots with weight below 80 g. Peixoto et al. (1989) found that the Brazlândia Roxa was the later cultivar and it showed the highest yield of scrap when harvested at 152 days. Regarding to rainfed experiment, there was a commercial yield ranging from 8.2 to 17.6 t ha^{-1}. Moreover, Thompson, Smittle and Hall (1992) comment that marketable yields increased with applied irrigation amounts until a total water application of 76% of pan evaporation was reached and then decreased rapidly with applied irrigation amounts. Weight loss and decay of roots during storage showed quadratic responses to irrigation amounts and were minimal at the irrigation level of maximum yields.

Water productivity (WP) and irrigation water productivity (IWP) depending on the harvest dates and irrigation depths is shown in Table 4. The WP decreased as water depth increased from $T_{0.25}$ to $T_{1.0}$. The WP was higher in $T_{0.25}$ due to the yield increase and it showed the highest values between 120 and 150 DAP, agreeing with the optimal harvest period. The difference in WP of 150-210 DAP, ranged from 4.3 to 20%, in $T_{0.25}$ and T_{100}, respectively. WP at T_0 was similar to $T_{0.75}$ due to the increase in yield in T_0 and the decrease in $T_{0.75}$. Mantovani et al. (2013) studied different irrigation depths and efficient water use in two sweet potato cultivars and they claimed that the increase in the applied water depth resulted in increased water use efficiency up to a maximum of 16.1 kg m^{-3}, with the application of 301.8 mm for the Amanda cultivar and 20.0 kg m^{-3}, with the application of 332.4 mm for Duda cultivar. Therefore, these values represent the depth of maximum water use by the studied sweet potato cultivars.

The root diameter and length of sweet potato as a function of the harvest dates and irrigation depths are shown in Figure 3. The largest diameters were found at 90, 120, and 210 DAP in T_0 and the lowest diameter was found at 90 DAP in $T_{0.5}$. The largest length was at 210 DAP in $T_{0.5}$. Regarding the values, the lower length values were observed in the roots with greater diameter values. Moreira et al. (2011) studied morphophysiological and productive traits of eight sweet potato cultivars. They

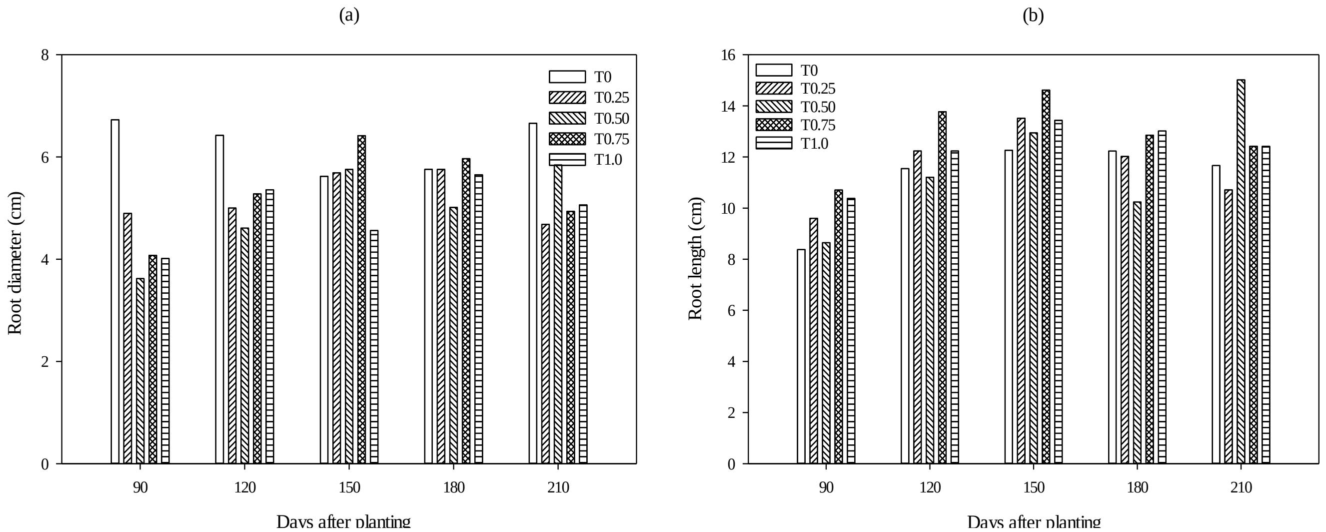

Figure 3. (a) The diameter and (b) length of sweet potato root according to harvest dates and irrigation depths.

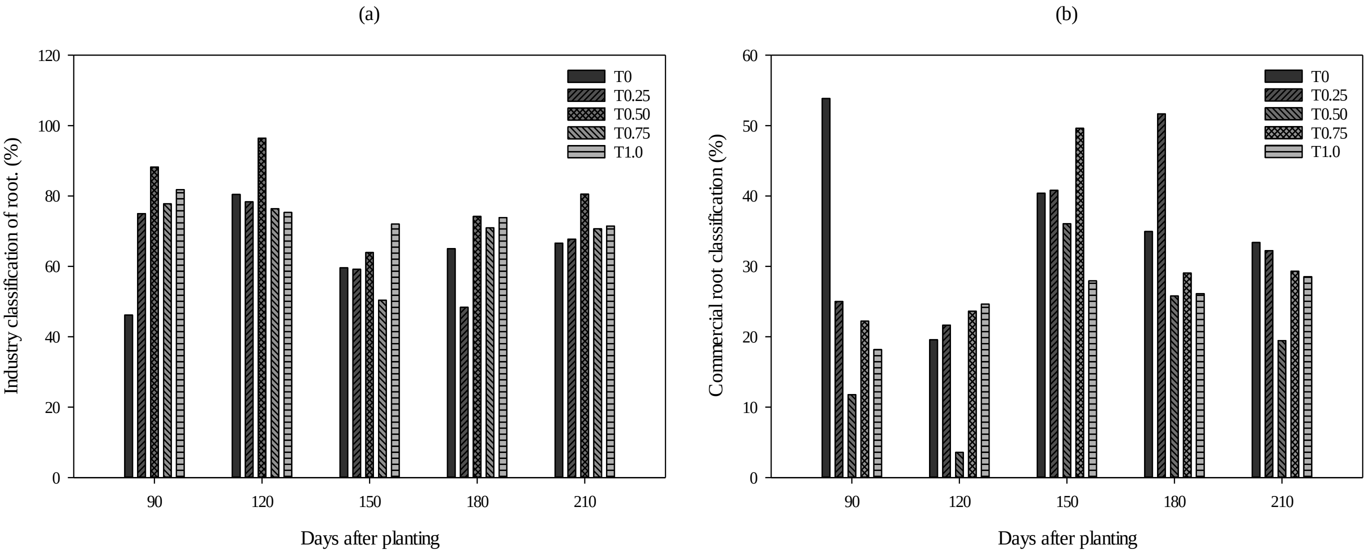

Figure 4. Classification of (a) industrial and (b) commercial roots of sweet potato according to harvest dates and irrigation depths.

observed that Paraná and Coquinho cultivars obtained the lowest length values, with 8.5 and 8.3 cm, respectively, and with the largest diameter values (5.7 cm in both cultivars). Meantime, the roots of ESAM 2 cultivar, which is included in the group of the longest roots (12.3 to 12.1 cm), were thinner (4.4 cm). Cardoso et al. (2005) evaluated 16 sweet potato clones and also evidenced this behavior and this clones had a mean length value of the roots of 13.9 cm.

The sweet potato root classification according to harvest dates and irrigation depths is shown in Figure 4. In this research, only two classifications (Industrial and Commercial) were done because the ethanol industry processes any type of classification. At all harvest dates and irrigation depths, industrial production exceeded the commercial one. Resende (2000) reported the harvest date influence on sweet potato cultivars under rainfed conditions performing harvests at 150 and 200 DAP. The authors assessed the following traits: commercial yield (roots weighing 100 to 800 g), scrap (roots below 100 g, cracked, deformed, greenish, brocade, and with veins), medium weight of commercial root, and commercial roots classification in percentage (Type 1- roots weighing 100 to 400 g and Type 2- roots weighing 400 to 800 g). Silva and Lopes (1995) verified that the harvest date did not change the commercial roots weight. However, they

Table 5. Total starch and crude protein (CP) in dry matter of sweet potato according to harvest dates and irrigation depths.

Treatment	Days after planting									
	90		120		150		180		210	
	Starch	CP	Starch	PB	Starch	PB	Starch	PB	Starch	PB
T_0	65.8	2.9	67.1	3.3	71.7	3.6	52.3	3.1	54.6	3.5
$T_{0.25}$	68.1	3.7	69.2	3.8	73.8	3.7	58.6	3.8	66.5	4.4
$T_{0.50}$	66.4	3.4	67.9	3.5	72.1	3.4	64.0	3.5	60.1	3.5
$T_{0.75}$	62.6	4.8	63.6	4.9	67.4	5.5	67.9	4.3	59.8	3.9
$T_{1.0}$	69.9	3.7	70.5	3.9	74.9	4.7	63.4	3.1	60.1	4.2

observed significant effect among cultivars, wherein the ESAM 3 had 257.0 g per commercial root, higher than the roots weight of the other cultivars and it was classified as Extra A, having possibly better commercial acceptance. Silva et al. (2015) studied the sweet potato cultivars performance for traits related to the root yield. In 2012, the authors observed that Beauregard cultivar stood out for the number and weight of roots. However, this cultivar did not show the greater values for average commercial roots weight that year, averaging 390 g. Good performance for these traits was repeated in 2013, along with the BRS Rubissol cultivar. The average commercial roots weight, the average value presented by the cultivars was 470 g in 2012, and 440 g in 2013. Those values were slightly above the ideal commercial size, which is 200 to 400 g (Miranda, 1989). Thus, the harvest date can be advanced for these cultivars, although the optimal size may vary depending on market requirements (Queiroga et al., 2007).

The total starch and crude protein in dry matter in function of harvest dates and irrigation depths are shown in Table 5. Starch content and crude protein were influenced by harvest dates and irrigation depths. In all treatments, starch content and crude protein were increased up to 150 DAP, showing the highest concentration at this date. Thereafter, they began to decline, where the starch content obtained lower values at 90 DAP. The irrigation depth influenced the starch content and crude protein, with the highest and lowest values of starch content in $T_{1.0}$ (150 DAP) and T_0 (210 DAP) and crude protein in $T_{0.75}$ (150 DAP) and T_0 (90 DAP), respectively. Tubers presented starch granules and variable amounts of sugar, depending on environmental conditions, harvest dates, and variety.

As stated in Braun et al. (2010), starch corresponds from 60 to 80% of dry matter and sugars: glucose, fructose, and sucrose are the major carbohydrates present in the tubers. As reported by Silveira (2008), the conversion into ethanol takes around 160 L t^{-1} for sweet potato clone samples with an average yield of 65.5 t ha^{-1} and average starch concentration of 24.4% in natural weight (NW). Starch content in plant roots may fluctuate depending on the fertilization. Therefore, the study and knowledge of the influence of this factor in the accumulation of starch content in plant roots will provide quality and yield improvements (Malavolta, 2006). Júnior et al. (2012) in the study of productive and qualitative characteristics of vines and roots of sweet potato, the crude protein contents in the roots of the evaluated genotypes were similar among themselves and ranged from 3.9 to 4.6% and they were also similar to the results found by Leonel et al. (1998), which reported crude protein content of 4.6% and higher than those found by Batistuti et al. (1992), of 1.1 to 1.7%, analyzing eight sweet potato cultivars. Lázari (2011) evaluated agronomic and physicochemical traits of 100 industrial sweet potato accesses of the breeding program in laboratory. They used fermenting measurer and obtained average ethanol yields of 151.67 and 234.33 L t^{-1} of root. Moreover, Thompson et al. (1992) comment that the glucose content was maximum at a total water amount of 94% of pan evaporation and fructose content decreased with increased amounts of irrigation.

Conclusions

Sweet potato was influenced by different applied irrigation depths and harvest dates, with an increase in starch content and a decrease in yield. The best harvest date was among 120 to 150 days after planting, where the variety demonstrated the highest yield potential in all evaluated variables. The most efficient water productivity was in the treatment 0.25 of evapotranspiration. In the studied conditions, sweet potato did not require irrigation with the established strategy, but more research is necessary on other frequencies and irrigation strategies. Due to the hardiness of the crop, low cost management, short cycle, and good starch production, sweet potato demonstrates feasibility for conversion to biofuels, being an alternative to the diversification of energy sources.

Conflict of Interests

The authors have not declared any conflict of interests.

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Effect of crop type and cultivar surface area on rates of decomposition in soils

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Sustaining the productive capacity of soils has raised interest in the maintenance of soil organic matter through management practices and use of crop residues. While the impact of management practices has been studied, little is done to understand how the charateristics of the residue itself impact the decomposition at the soil surface. This study relates the chemical composition and the surface area of the aboveground residue to the decomposition rates for three cultivars each of three crops: cotton, peanut and sorghum. The rates were determined by mass loss. Change in the residue specific surface area to mass loss was also measured. Findings show that after 14 days, the aboveground residue for the three crops were from the most rapid loss to the slowest: cotton (43%) > peanut (32%) > sorghum (24%). Changes in the specific surface area-to-mass ratio were from the slowest to the most rapid loss: cotton (1.60×10^{-4}) > peanut (1.50×10^{-4}> sorghum (1.20×10^{-4}). Since varietal differences within crops have led to variation in decomposition rates, cultivars with slower decaying residues might be recommended for C sequestration and for erodible lands in semi-arid zones of the Sahel. Likewise, crop residues with faster decomposition rates can be recommended for soil fertility improvement.

Key words: Decomposition rate, crop type, crop residue, chemical composition, specific surface area-to-mass ratio.

INTRODUCTION

Maintaining crop residue on the soil surface is an effective and cost-effective practical method for controlling wind and water erosion. It provides a large potential to sequester C in the soil, which may be preferable to storage in vegetation due to their longer residence times and less risk of a rapid release (Lal et al., 1999). It also offers an outlook on targeted strategies for cropping and farming systems to cope and adapt to climate change and variability, as well as soil fertility challenges within the socio-ecological context (Callo-Concha et al., 2013).

In many areas of the world, insufficient amounts of residue are produced to provide adequate erosion protection. While in some areas, the accumulation of crop residues is frequently viewed as a nuisance to crop

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establishment and growth, and a disposal problem, in other areas, there are not enough surface residues due to low productivity, burning for management purposes or utilization as animal feed or even fuel (Diack et al., 2000).

In West Africa, cotton, peanut and sorghum crops cover 50 to 60% of the rainfed areas (Laube, 2007), which explains why they have been chosen for this study. Through its importance as a cash crop, cotton (*Gossypium hirsutum*), has received wide attention from the African governments, especially in the Benin and Burkina Faso (Slingerland, 2000). The Centre de Cooperation International en Recherche Agronomique pour le Developpement (CIRAD) reported good adoption of improved varieties, mineral fertilization, phytosanitary measures and animal traction in the framework of (a) close research-extension-farmer relationship, (b) provision of input credits, and (c) guarantee of market outlets (The World Bank, 2002; Gray, 2005; Gaiser et al., 2010).

Peanut (*Arachis hypogea*) is the main legume cultivated in the Sudan Savanna and, together with other leguminous species, makes large contribution to fulfilling the protein demand of the local population and the provision of high quality fodder for livestock (Slingerland, 2000). Peanut is a preferred legume due to its ability to produce well under soil-moisture- deficient conditions, as well as being a source of external income since it is well sold in the market and even exported (Ntare et al., 2007).

Sorghum (*Sorghum bicolor*, *Sorghum vulgare*), commonly called ‘guinea corn’ or ‘red millet’, is widely cultivated. It originated in eastern Africa where its major variability can be found. Accordingly, sorghum has developed various morphological and physiological adaptations, such as drought resistance. It performs well at rainfall levels (400 to 600 mm/year) too low for maize. The response of sorghum to management is diverse and depends on the variety. Local varieties are poorly responsive, but improved ones respond well to fertilization. Normally it is cultivated in combination with other crops (Schipprack and Abdulai, 1992).

Crop residues are an important source of organic matter that can be returned to soil for nutrient recycling, and improve soil physical, chemical and biological properties (Kumar and Goh, 2000). They contain all mineral nutrients, the content of which varies among crop species depending on the fertility of the soil (Brennan et al., 2004). These residues should be returned to the soil and should be spread uniformly over an entire field to prevent nutrient and organic C in the soil (Lal, 2005). Given that a decrease in soil fertility is a major constraint to productivity, investing in practices leading to soil fertily enhancement is likely to general large returns. In recent years, increased concerns for healthy food production and environmental quality, and increased emphasis on sustaining the productive capacity of soils, have raised interest in the maintenance and improvement of soil organic matter through appropriate land use and management practices (Loveland and Webb, 2003; Puget and Lal, 2005; Whitbread et al., 2003).

It is however, difficult to predict how much of the nutrients in the residue will become available to crop during a given time because of the complex processes governing residue decomposition and nutrient release (Iyamuremye et al., 2000). In addition, the nature of crop residue and their management can significantly affect the amount of nutrients available for subsequent crop as well as the content and quality of soil organic matter (Kumar and Goh, 2000; Yadvinder-Singh et al., 2005). Effective management of crop residues in the field should conserve soil and its resources with minimal adverse effects on the environment (Conteh et al., 1998; Puget and Lal, 2005). For most soils, the higher the level of crop residue (stems, stalks, and leaves from the previous harvest) left on the surface of a field, the greater the benefits.

However, to optimize this effect, fundamental information is needed on residue decomposition and how the characteristics of the residue itself impact the decomposition rate. Wickings et al. (2012), found out that the chemical complexity of decomposing plant litter is a central feature shaping the terrestrial carbon (C) cycle, but explanations of the origin of this complexity remain contentious. How does litter chemistry change during decomposition and what roles do decomposers play in these changes? The rate of residue decomposition will determine the amount of soil surface covered during critical erosion periods throughout the year, as well as the amount of residues in top portion of the soil profile.

Plant residues consist of two parts: the aboveground portion, mainly composed of stems and leaves, and the roots. The aboveground biomass may be standing flat on the soil surface, or become buried through tillage and other management practices. The physical nature and the initial chemical composition of the plant residues largely determine the ability of microorganisms to assimilate them. In the traditional agronomic literature, the C/N ratio has been assumed to be a controlling factor, while in the traditional forestry literature, the lignin-to-N has been considered most important (Abril and Bucher, 2001). However, the C/N ratio is apparently not the determining factor, nor is the lignin-to-N ratio solely responsible (Dempsey et al., 2013). Decomposition rate for plant residue varies between plant species and between cultivars within species (Stott, 1993). Most knowledge about crop residue decomposition is based on above-ground residue, mostly winter wheat. Increased soil organic matter (SOM) in semi-arid environments, through optimal soil management practices, could be beneficial to food productivity and erosion control in poor and degraded areas, in addition to the removal of atmospheric CO_2 (Ringius, 1999). This practice may be new to most smallholder farmers. In semi-arid areas, crop residues serve as forage for livestock during the dry season. The land use right of the farmer is limited to the growing season. Later, the fields are opened for common grazing. Apart from this, crop residues serve also as construction material or fuel. To change this situation, farmers have to be convinced of the advantage of leaving residues in the field to cover the soil surface and alternatives have to be shown.

The specific-surface-area-to-mass ratio (k) represents a fraction of an area (ha) of soil covered by one kg of residue and is specific for a crop type. The k value is a conversion constant (ha kg^{-1}) used in an equation for converting residue mass to cover (Gregory, 1982):

$$C = 1\text{-}e\ (^{-km}) \quad (1.0)$$

where C = fraction of the surface cover remaining and m = mass (kg ha^{-1}) of residue present on the surface.

The Gregory equation is currently used in all the USDA erosion MODELS: WEPP (Water Erosion Prediction Project), WEPS (Wind Erosion Prediction System), RUSLE (Revised Universal Soil Loss Equation), and RWEQ (Revised Wind Erosion Equation).

The residue mass-surface cover relationship is closely related to the levels of residues, and considerable decomposition of mass may occur before a large decrease in cover is measured (Steiner et al., 1993). For residues having high proportion of leaf material following harvest, there may be tremendous loss in mass with little loss in cover, because leaf material decomposes rapidly and is light compared to stem material. Stem will loose mass, not surface area.

Therefore, understanding the mechanisms of residue decomposition is necessary for developing a viable crop residue management system for a better land management leading to a sustainable agricultural productivity and ultimately food security. The objectives of this study were to: (i) determine decomposition rates for cotton, peanut and sorghum above-ground residues by mass loss; (ii) determine how initial physical and chemical properties of the residues impact the decomposition rates; (iii) determine if differences in decomposition exist between plant cultivars within a species; and (iv) determine changes in the mass-to-specific surface area during decomposition.

MATERIALS AND METHODS

Soil

A Russell silt-loam (fine-silty, mixed, mesic Typic Hapludalf) soil was used in this study. It was obtained from the Ap horizon at the Purdue Agronomy Research Center in West Lafayette, IN. The soil was air-dried (to minimize microbial action before use), crushed to pass a 2-mm mesh screen, and then stored until use. The soil had a pH_{water} of 5.3, a total C content of 7.8 g kg^{-1}, and a total N content of 1.2 g kg^{-1}.

Plant materials

Plant from three field-grown crops: cotton (*G. hirsutum*), peanut (*A. hypogaea*) and sorghum (*So. bicolor*) were collected at maturity. Each crop was represented by three genetically different cultivars. These cultivars are the following: cotton (DLP-5660, DP-5215 and HS-46), peanut (Florunner, NC-7 and NC-11) and sorghum (Triumph-266, GW-744BR and NKing-300). For each cultivar, the plant material was collected from the aboveground residue (leaves and stems). These components were used to determine the residue decomposition rate. Plant residue samples were collected by USDA-SCS personnel from fields in several states, within one or two days of harvest in order to be in unweathered condition and maximize their use. Five plant samples, representative of the whole field, were selected: one from the center and four from 4 corners, avoiding the end rows. When removing the whole plant from the ground, care was taken so that the roots within the top 10 to 20 cm of the soil did not break apart. The residues were shipped overnight to the National Soil Erosion Research Laboratory (NSERL) in West Lafayette, IN. The leaves and stems (above-ground biomass) were separated from the roots. The residues were gently washed with water to remove any remaining soil and air-dried before chemical analysis. These components were used to determine the residue decomposition rates and the surface area.

Composition analysis

Each plant residue component was chemically analyzed for total C content, total N content, simple sugar content and structural and non-structural contents. Total C and N were measured by dry combustion (Model CHN-600; Leco Corp., St Joseph, MI). Hemicellulose, cellulose and lignin contents were determined by sequential fiber analysis (Goering et al., 1970). This fiber analysis system was designated to provide estimates of forage fiber composition. Sucrose and fructose were measured colorimetrically from a 1:1 weight-volume ratio of finely ground residue and 50% ethanol solution. For sucrose, 100 µl of 30% KOH was added to destroy the sugars, whereas for fructose, 3 ml of concentrated HCl was added plus 1 ml of 0.05% resorcinol reagent.

Plant residue mass loss experiment

The mass loss experiment consisted of a split-split plot design of 3 crop types as main plots and 3 cultivars as subplots; leaves and stems as the last split. Treatments were in triplicate. Each treatment consisted of leaves and stems in the same proportion as was present in the aboveground biomass after harvest.

Residues were cut into 4 to 5-cm long and the pieces were spread evenly on the soil surface in a 10 by 7.5 cm^2 polystyrene dish. Optimum moisture conditions were assumed to be the water content at -1/3 bar water potential as equalled to 60% water holding capacity, plus 300% of the residue mass (Myrold et al., 1981). After the appropriate amount of water was added, the incubation dish was loosely wrapped with a food service film (PYA/Monarch, Inc., Greenville, SC), to allow some aeration. The samples were incubated at 22 ± 1°C.

Samples were withdrawn on days 3, 7, 14, 28, 56 and 84 of the incubation for mass measurement. At each destructive sampling, the incubation mixture was oven-dried at 40°C, for 48 h. When dry, the residues were carefully separated from the soil, gently washed to remove the soil particles and put back into the oven at 40°C for 48 h. The residues were weighed then placed into crucibles for ashing at 800°C for 2 h.

Measurement of specific surface area-to-mass ratio

Specific surface areas for the leaves and stems were measured using a digitizer (Summagraphics) and AutoCad. As decomposition

Table 1. Loading rates of crop residues added to soil for decomposition study.

Crops	Leaves		Stems	
	g of residue per 100 g of soil	%	g of residue per 100 g of soil	%
Cotton	0.90	45.0	1.10	55.0
Peanut	0.53	26.5	1.43	73.5
Sorghum	0.85	42.5	57.5	57.5

proceeded, the ration between the specific surface area and the mass remaining was calculated at each sampling time.

The equation used to convert residue mass to cover is from Gregory (1982):

$$C = 1 - e^{(-km)} \quad (1.0)$$

where C is the fraction of the surface cover remaining and m is the mass (kg ha-1) of residue present on the surface.

The constant k can be derived from the following equation:

$$k = - \log (1-C)/m \quad (2.0)$$

Statistical analysis

Statistical analysis of the data was done to determine differences among treatments, using the PC-SAS, Version 9.01 (SAS Inc., Cary, NC). Comparisons between treatment means were made at the P=0.05 level using the Student-Newman-Keuls's multiple range test procedure.

RESULTS

Initial chemical composition

The mean concentrations of total C and N, simple sugars, hemicellulose and lignin (Table 2) were significantly different between the aboveground biomass residues for cotton cultivars DLP-5690, DP-5215 and HS-46. Total C, total N, hemicellulose and lignin contents were 103, 163, 190, and 139% greater, respectively for DLP-5690 than for DP-5215, whereas, simple sugars content was 78% lower. For HS-46 aboveground residues, the mean concentrations of total C and N, simple sugars, hemicellulose and lignin were 105, 160, 147, 197 and 128% higher, respectively than for DP-5215.

As for sorghum, the mean concentrations of total C and N, simple sugars, hemicellulose and lignin were significantly different between the aboveground biomass residues for Triumph-266, GW7-44BR and NKing-300. Total C and N and hemicellulose contents were 103, 150 and 157% greater, respectively for GW7-44BR than for Triumph-266, simple sugars content was 26% lower. For NK-300 aboveground residues, the mean concentrations of total C and N, hemicellulose and lignin were 2, 38 and 84% lower respectively than for GW7-44BR, whereas, simple sugars content was 150% greater. Table 3 indicated significant differences in initial chemical composition between cultivars within crops.

Initial specific surface area

For cotton, the specific surface area (Table 3) of the aboveground residues before incubation is not significantly different between cultivars (Figure 6). The specific surface area of DLP-5690, DP-5215 and HS-46 leaves was 101, 73 and 85 greater than the stems, respectively. No peanut cultivar was significantly different from one another for the aboveground specific surface area (Figure 7). However, the specific surface area of the leaves was significantly greater than the stems by 95% for Florunner, 235% for NC-7, and 113% for NC-11. As for sorghum, the initial specific surface area of the leaves and stems (Table 3) showed significant differences between cultivars except for GW-744BR. Triumph-266 leaf specific surface area was greater by 45% than that of the stems. GW-744BR leaf specific surface area was not significantly different from that of the stems (Figure 8). In the other hand, NKing-300 leaf specific surface area was 87% higher than that of the stems.

For Triumph-266, the specific surface area was 18% greater than that of GW-744BR, but 9% lower than that of NKing-300. As for GW-744BR, the leaf specific surface area was 23% lower than that of NKing-300.

Initial aboveground residue mass

For all crops and each cultivar, aboveground residue mass was a combination of stem and leaves with different proportions (Table 1). Within cotton, cultivar HS-46 aboveground residue mass was higher than those of DLP-5690 and DP-5215 cultivars. For peanut, there was no significant difference in aboveground biomass between cultivars. On the other hand, GW-744BR sorghum cultivar, presented a greater aboveground residue mass than those of Triumph-266 and NKing-300.

Change in mass loss

In determining mass loss, the aboveground residues composed of leaves and stems (Table 1), were monitored in terms of changes in mass loss. For cotton cultivars, the rate of mass loss of the aboveground residues was significantly different between cutivars (Figure 2). HS-46 had a faster breakdown rate, 38%, followed by that of DP-5215, 30% and DLP-5690, 26%.

Table 2. Initial chemical composition of the aboveground biomass residues.

Crop	Cultivar	Total C	Total N	Sugars	Hemicellulose	Lignin
		g kg^{-1} residue				
	DLP-5690	448.9^{a}	31.4^{a}	18.1^{c}	252.4^{b}	112.1^{a}
Cotton	DP-5215	437.1^{b}	19.3^{b}	23.1^{b}	133.1^{c}	80.7^{c}
	HS-46	457.3^{a}	30.9^{a}	34.0^{a}	262.5^{a}	103.3^{b}
	Florunner	450.4^{a}	13.4^{b}	89.9^{a}	176.6^{a}	64.8^{a}
Peanut	NC-7	455.2^{a}	20.0^{a}	87.7^{a}	140.0^{b}	42.3^{c}
	NC-11	450.4^{a}	18.8^{a}	66.8^{a}	108.2^{c}	50.4^{b}
	Triumph-266	438.2^{c}	11.9^{b}	41.1^{b}	208.3^{c}	47.6^{a}
Sorghum	GW7-44BR	452.5^{a}	17.8^{a}	32.5^{c}	327.1^{a}	32.5^{b}
	NKing-300	447.9^{b}	6.9^{c}	48.7^{a}	273.7^{b}	48.2^{a}

Values followed by the same letter, within crops, are not significantly different by the Waller-Duncan's multiple range test at P = 0.05.

Table 3. Relative initial mass and specific surface area of the residue components.

Crops	Cultivars	Relative initial mass (%)		Relative Initial specific surface area (%)	
		Leaves	Stems	Leaves	Stems
	DLP-5690	38.5^{a}	43.9^{ab}	66.8^{a}	33.2^{a}
Cotton	DP-5215	34.4^{b}	49.1^{a}	63.4^{a}	36.6^{a}
	HS-46	40.8^{a}	45.9^{ab}	64.9^{a}	35.1^{a}
	Florunner	24.3^{b}	69.5^{a}	65.4^{b}	33.6^{a}
Peanut	NC-7	27.8^{ab}	67.5^{ab}	77.0^{a}	23.0^{b}
	NC-11	29.4^{a}	65.1^{b}	68.0^{b}	32.0^{a}
	Triumph-266	36.9^{a}	44.5^{b}	59.2^{b}	40.8^{b}
Sorghum	Gw-744BR	33.2^{b}	52.5^{a}	50.2^{c}	49.8^{a}
	NKing-300	36.2^{a}	46.9^{b}	65.1^{a}	34.9^{c}

Values followed by the same letter, within crops, are not significantly different by the Waller-Duncan's multiple range test at P = 0.05.

Peanut aboveground residue mass loss did not present any significant difference from one cultivar to another in the percent mass remaining during the first 14 days (Figure 3). As for sorghum (Figure 4), cultivars showed 32% of mass loss for Triumph-266, 24% for GW-744BR and 20% for NKing-300 in the early decomposition phase. Triumph-266 cultivar presented a significant difference in aboveground residues mass loss compared to the other two cultivars (Figure 4). There was no difference in decay rates between the aboveground residues for the three cultivars (Figure 4). Significant differences in mass remaining were observed between the mean mass loss of the cultivars of cotton, peanut and sorghum aboveground biomass in the early decomposition phase. Overall, cotton mean residue mass loss was greater, 45%, than those of peanut, 40%, and sorghum, 34% (Figure 1).

DISCUSSION

The decomposition rates for all cotton (Figures 1 and 2), peanut (Figures 1 and 3), and sorghum (Figures 1 and 4) cultivars followed the pattern for Michaelis-Menten first-order kinetics. The rapid increase in mass loss during the first 14 days was probably due to the high total N content, the high level of readily available C in the form of extractible sugars or a combination of the two (Table 3). Kinetically, the mass loss from the residues studied exhibited a linear dependence on the chemical composition of the residue. The rapid disappearance of these soluble compounds was probably related to a quick

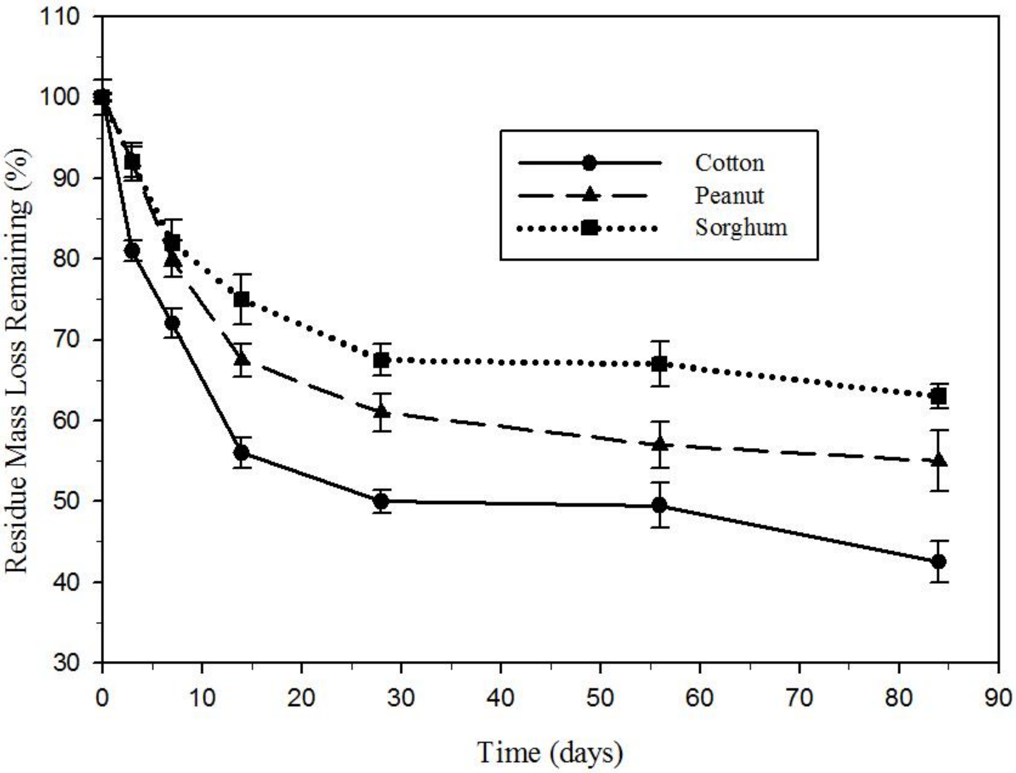

Figure 1. Changes in aboveground residue mass loss over time for cotton, peanut and sorghum crop species. Bars represent standard deveiations at given time.

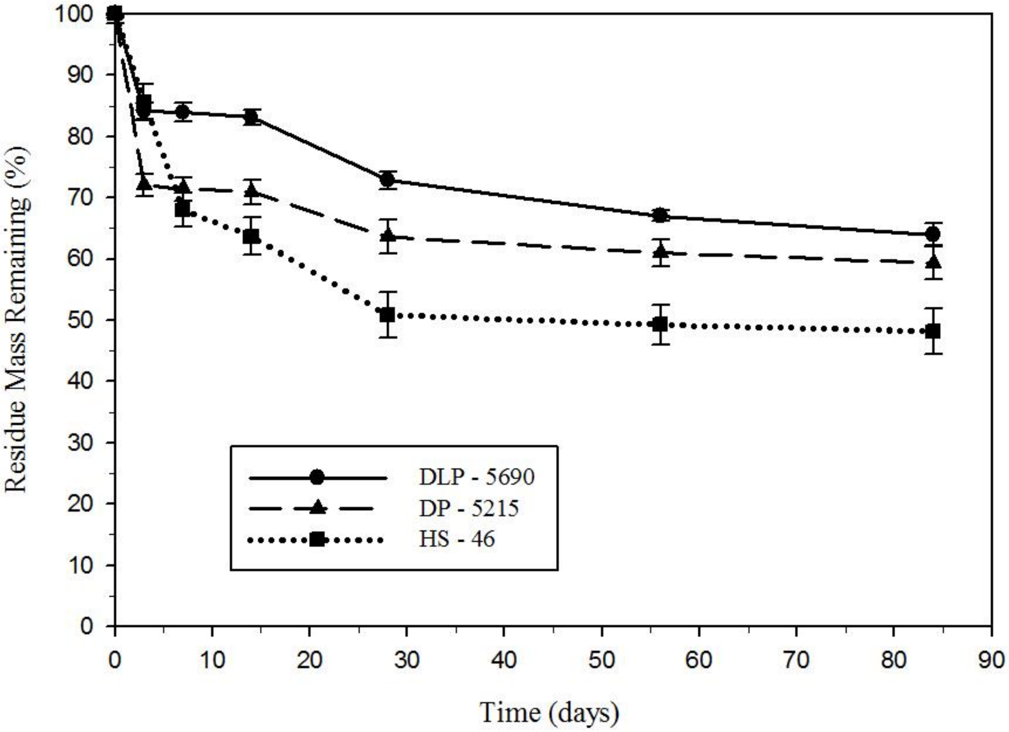

Figure 2. Changes in aboveground residue mass loss over time for cotton crop species. Bars represent standard deveiations at given time.

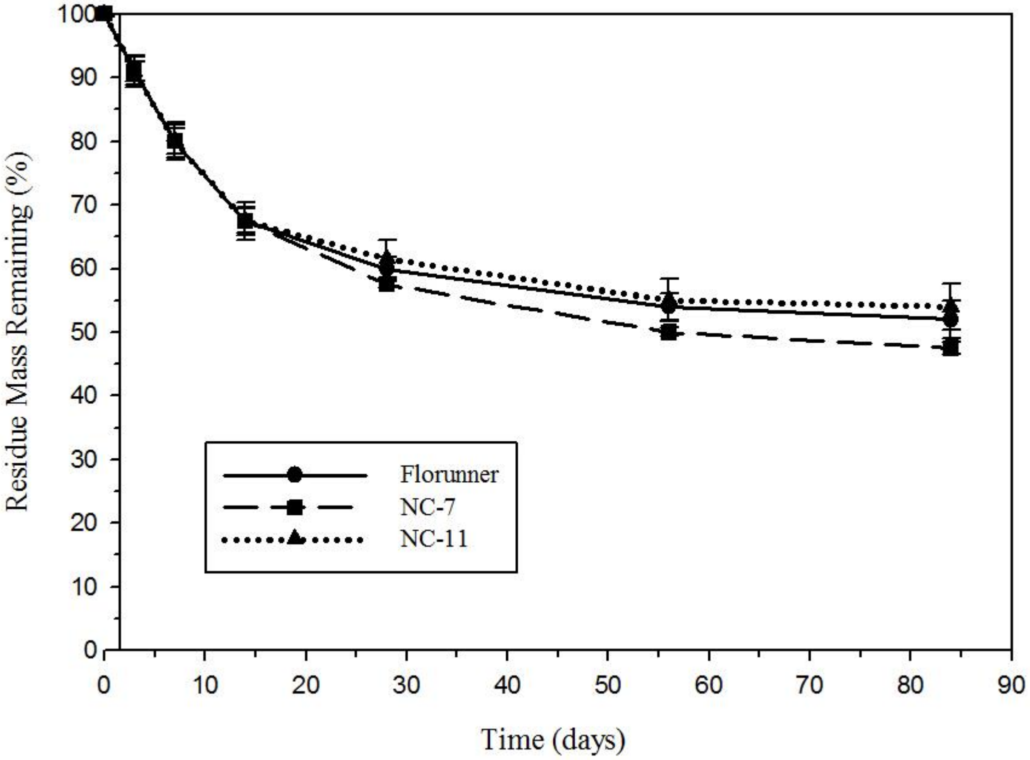

Figure 3. Changes in aboveground residue mass loss over time for peanut crop species. Bars represent standard deveiations at given time.

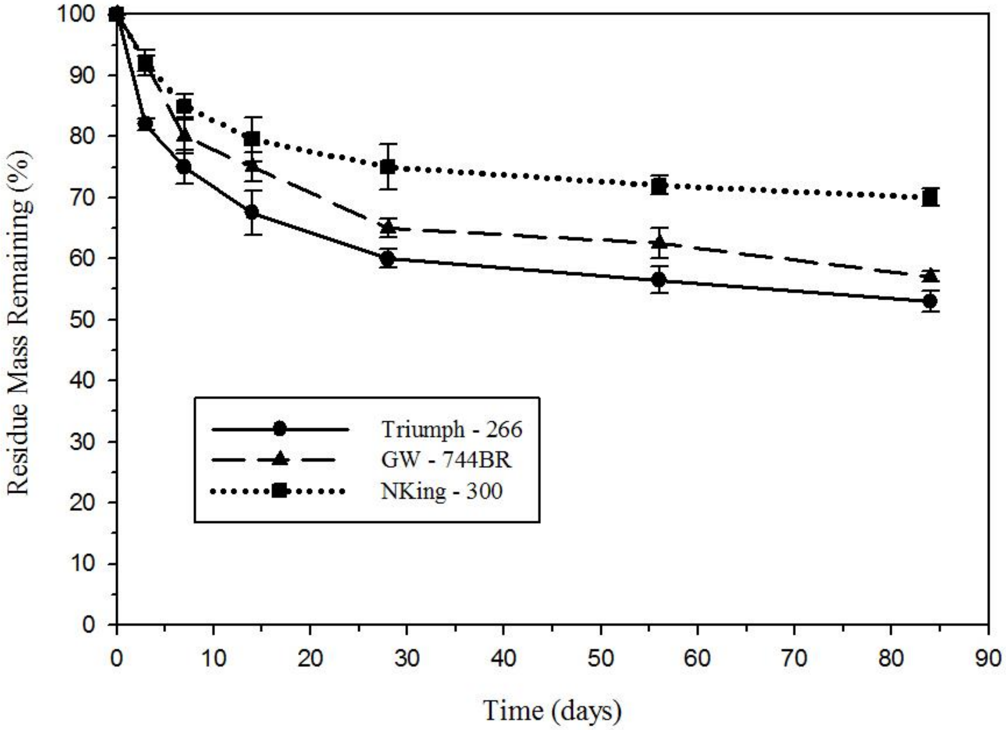

Figure 4. Changes in aboveground residue mass loss over time for sorghum crop species. Bars represent standard deveiations at given time.

build up of the microbial activity, which would increase the mass loss. Also, the readily available C and N components in the crop residues might provide the initial energy and nutrients necessary to activate the microorganisms that are responsible for the degradation of the less readily available components of the residue (Sall et al., 2007). The levelling off phase of the mass loss, from all three crops, between days 15 and 28, would be the period during which hemicellulose was the main fraction available to the microorganisms (Figures 1, 2, 3 and 4). As decomposition process proceeds, the mass loss slows down, following an exponential trend, probably due to change in chemical composition of the remaining residue available to the microorganisms (Rinkes et al., 2013). In this phase of the decomposition, the hemicellulose fraction probably disappears initially at a rapid rate, but the subsequent degradation appears to be slower. Residue recalcitrance controls decomposition and soil organic matter turnover (Machinet et al., 2009). In addition, the presence of lignin and cross-linking phenolic acids is well known to regulate enzyme access to cellulose and hemicelluloses in forage digestibility and bioreffinery studies (Lam et al., 2003; Berlin et al., 2006) and appears to affect decomposition in soils (Machinet et al., 2011b; Talbot et al., 2012). Such degradation of hemicellulose is more marked when the environment is aerobic, and when there is availability of inorganic nutrients, especially nitrogen. At this stage of the decomposition process, there is probably not enough N or readily available C to keep the microbial activity at high level. As a result, there is a decrease in decomposition rate, resulting in a slower rate of mass loss (Elliott al., 1986; Stott, 1993; Iqbal et al., 2014). All residues types show the same trend and similar slopes in this portion of the curve, suggesting that the second phase of the decomposition is probably not a good element of comparison of mass loss. After 28 days of decomposition process, the remaining residues entered the third phase of the decomposition process. At this point, the slowly available residue components dominated the residue substrate. Lignin, known to be resistant to degradation, was probably the major remaining component. The rate and extent of lignin decomposition are affected by temperature, availability of nitrogen, and by constituents of the residues undergoing decay. At this stage of degradation, all the readily available nutrients are expected to vanish. Lignin is probably being decomposed by relatively slowly growing microorganisms. Consequently, microbial activity is very low. As a result, mass loss follows a quasi steady state for the rest of the decomposition. Lignin continues to disappear however. Cotton cultivar DPL-5690 and DP-5215 aboveground biomass (Figure 2) showed a great cumulative mass loss due to total N, lower hemicellulose and lignin cooncentation in the residue. In addition, lower lignin content plus high specific area-to-mass ratios for the aboveground residue provide with microorganisms better access to available C sources (Jensen, 1994). As for the HS-46 cultivar aboveground residues, the specific surface area-to-mass was probably too low in aboveground biomass to provide with microorganisms good access to available C sources. For all peanut cultivars (Figure 3), the aboveground residues showed quite high cumulative mass loss due higher simple sugar contents available to the microorganisms, combined with lower lignin concentration of the aboveground biomass. There was no difference in rate of breakdown of the aboveground residues between the three cultivars. The insignificant difference in sugar concentrations between Florunner, NC-7 and NC-11 aboveground residues (Table 2) certainly excludes any difference in their cumulative mass loss (Figure 3). Peanut is a legume, and the highest N level is concentrated not in the aboveground biomass, probably in the root system where the pods are produced.

The sorghum cultivar, GW7-44BR (Figure 4), showing a significant difference in mass loss between the aboveground residues had the highest total N, and the lowest simple sugars and lignin concentrations in the aboveground residues. For Triumph-266 and NKing-300 (Figure 4), high available C in the form of simple sugar concentration, associated with low hemicellulose content probably contributed to their higher mass loss level for the aboveground residues. These results were consistent with who observed that high levels of sugars in sorghum furnished the energy for multiplication of soil micro-organisms, which compete with plants for the available soil nitrogen. The data (Tables 2 and 3) support the differences in cumulative mass loss among residues. These results agreed with Collins et al. (1993) data in their study of decomposition of winter wheat residues. great increasing trend of breakdown.

Specific surface area-to-mass relationships, represented by a k value, is a specific surface area-to-mass ratio with dimension of ha kg^{-1} of residue. In Gregory's (1982) Equation 2, k is specific for a given crop and considered to be constant over time. Between cotton, peanut and sorghum crops, k was noticed to be significantly different (Figure 5). The initial k value for cotton was greater, 42×10^{-5}, than peanut and sorghum, 23×10^{-5} and 18×10^{-5}, respectively. In the first 14 days, change in specific surface area-to-mass ratio was relatively rapid for cotton and peanut residues but change in sorghum was quite slow. Stott et al. (1994) found a k value of 23×10^{-5} for corn from field data. This was consistent with the range of values from this study as the three crop species used, sorghum is the crop that is physiologically and morphologically closest to corn and both are monocotyledons. Compared to corn, sorghum has a lower osmotic concentration of the leaf juices, but the stalks, crown and root juices are higher in sorghum (Leonard et al., 1963). In addition to its juicy stem, sorghum leaf area is smaller than that of corn. Therefore, sorghum residue decomposition may be somewhat faster

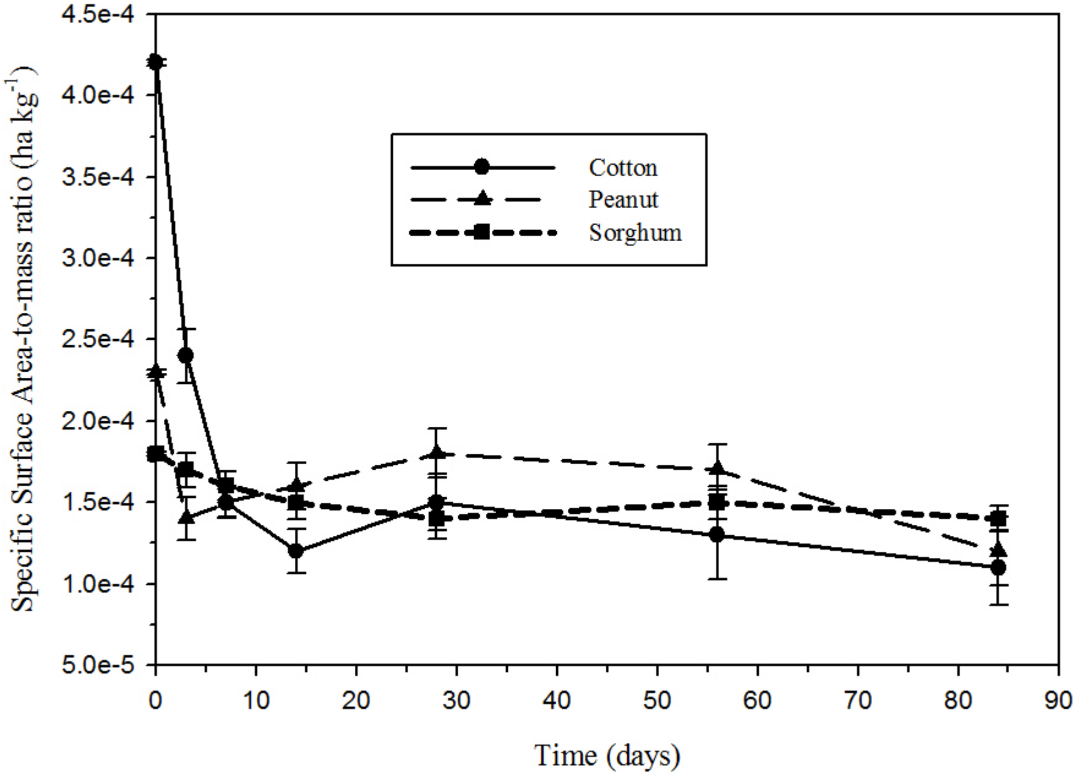

Figure 5. Specific surface area-to-mass ratio for cotton, peanut and sorghum aboveground residues over time. Bars represent standard deviations at given time.

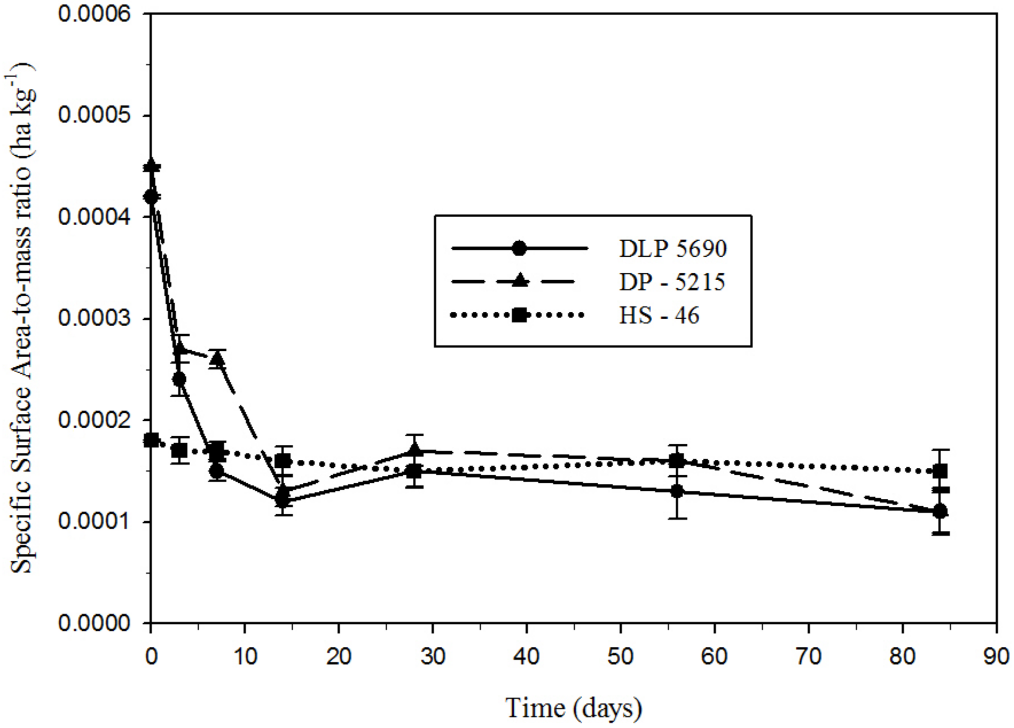

Figure 6. Specific surface area-to-mass ratio for cotton aboveground residues over time. Bars represent standard deviations at given time.

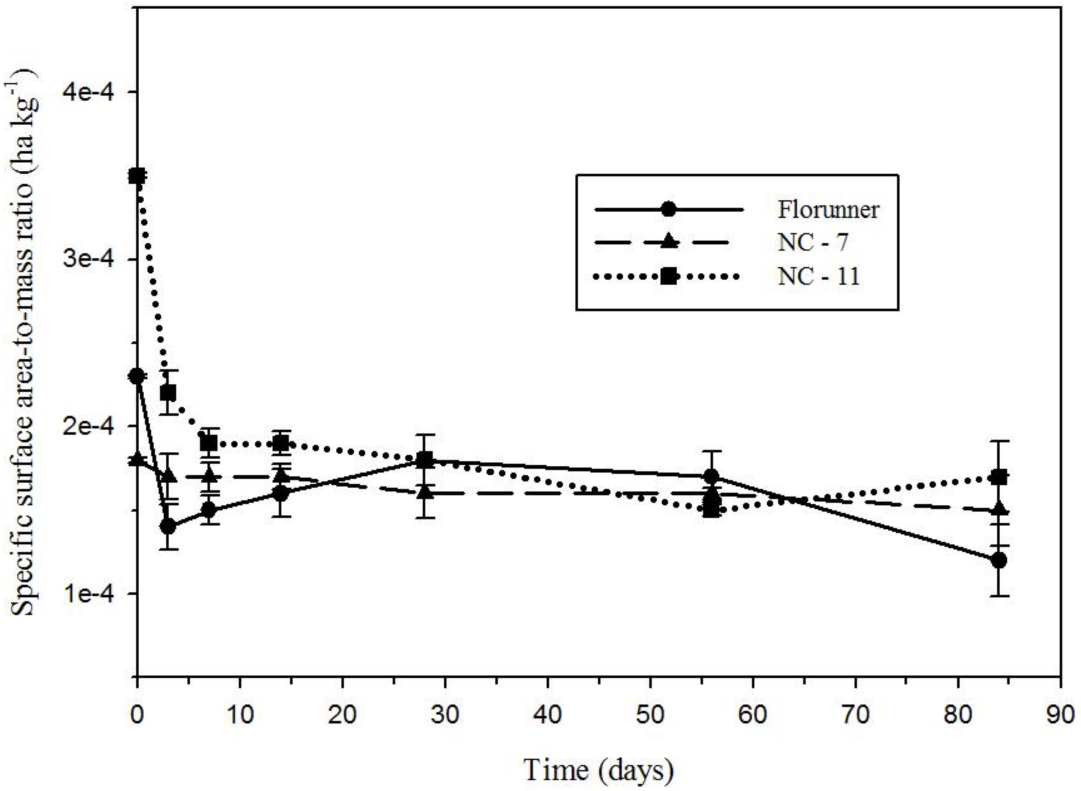

Figure 7. Specific surface area-to-mass ratio for peanut aboveground residues over time. Bars represent standard deviations at given time.

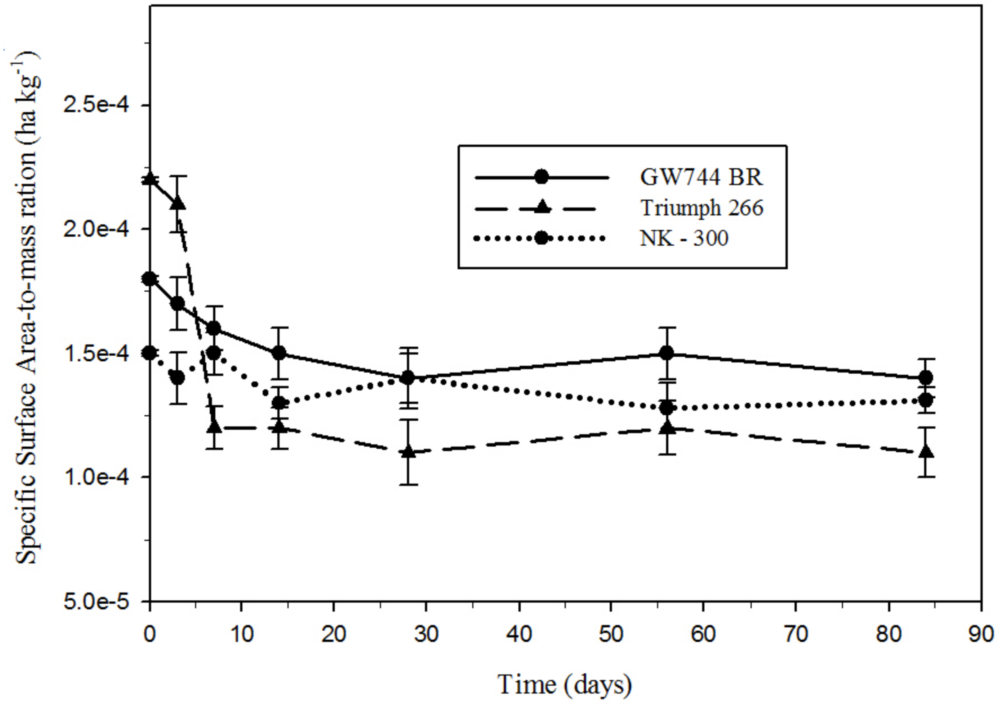

Figure 8. Specific surface area-to-mass ratio for sorghum aboveground residues over time. Bars represent standard deviations at given time.

than corn. Consequently, a k value for sorghum should be lower, but close to that of corn residue. k was found to be a value specific to each crop species. It changes within a certain range over time, during the decomposition process because it is a ratio of specific surface area over mass of the decomposing residue (Equation 2). In this study, significant differences were observed between cultivars for cotton in the first 10-14 days, but to a lesser extent for peanut and sorghum cultivars. However, such significant difference in mean k values between cotton, peanut and sorghum species was consistent with its specificity to each crop (Stott, 1993).

Conclusion

The initial chemical and physical characteristics of the aboveground residues impacted the rates of decomposition. The decomposition rates determined by mass loss showed differences between cultivars, for cotton, peanut and sorghum. Due to their leguminous nature, the three peanut cultivars were decomposed rapidly, and were different in decay rates between them. The degradability of peanut aboveground residue was highest followed by cotton, while the sorghum aboveground decomposition fate was the slowest. The different decomposition rates for each crop did follow the same order in degradability for the aboveground residues. There was significant difference between the decomposition rates of the cotton and peanut roots. Changes in specific surface area-to-mass measurements showed significant différences between cultivars within cotton only, but there were differences between species as if k value was a constant specific for each crop. Determining residue decomposition, as used in a management program, can help solve soil degradation problems in the semi arid zones.

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Quality of seedless watermelon cultivated under different doses and phosphorus application forms

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Effects of doses and phosphorus application forms were studied on the postharvest quality in seedless watermelon hybrid 'Style'. For this, an experiment was conducted in Upanema/RN, Brazil, during the period of September to December 2013, in a randomized block at factorial scheme 5×2 constituting of five phosphorus doses applied in foundation (0, 76, 168, 275 and 397 kg ha^{-1} of P_2O_5) and foundation + fertigation (0+50, 26+50, 118+50, 225+50, 347+50 kg ha^{-1} of P_2O_5) with four replications. Fruit harvested at commercial maturity (78 days after sowing) were evaluated by average fruit weight (AFW), pulp firmness (PF), chroma index, hue angle, soluble solids content (SS), titratable acidity (TA), maturation index (MI), total phenols content (TP), vitamin C (VC), total sugars content (TS), reducing sugars content (RS) and pH. Among the quality parameters evaluated phosphorus application forms did not affect physical characteristics of fruit, but combination of application via foundation + fertigation increased VC, TS and MI. There was interactive effect of dose and phosphorus application form for the SS, TA, pH and TP. The dose of 50 kg P_2O_5 ha^{-1} applied only in fertigation significantly increased values of SS, TA and TP. It is concluded that low doses of P in cultivation and its application via foundation and fertigation improved the main quality characteristics of 'Style' watermelon.

Key words: *Citrullus lanatus*, fertigation, foundation fertilization, soluble solids.

INTRODUCTION

Watermelon belongs to Cucurbit's family, which has assumed an important position in the world market. Out of the 109.28 millions of tons of watermelon produced worldwide in 2013, China was responsible for 66.97% of this total, followed by Iran (3.61%), Turkey (3.56%), and Brazil (1.98%) (Faostat, 2015). In the last years, Brazilian

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production of watermelon showed significant increases, from 226,778 tons in 2000 to 2,171,288 tons in 2014 (Ibge, 2015). Commercial watermelons differ in cell ploidies, being classified as diploid (with seed) and triploid (seedless). In these days, seedless watermelon cultivation has aroused interest of producers, especially from those who look forward to attend the external market demand, where the product is widely accepted. Generally, seedless watermelon, comparing to watermelon with seed, presents a crispier texture and sweeter taste, given its firmer pulp (12.0 N vs. 9.9 N, respectively) and larger level of soluble solids (12.7 vs 10.5%, respectively), (Maynard et al., 2002; Leskovar et al., 2003).

Besides the 90% of water in the pulp, what makes it a very natural source of water for human hydration, watermelon is a natural source of antioxidants compounds, such as lycopene (42.7-102.4 mg kg^{-1}), vitamin C (105.2-239.8 mg kg^{-1}), phenolic (89-147.3 mg GAE kg^{-1}) and flavonoids (111.3-176.1 mg RE kg^{-1}), most important bioactive compounds present in the pulp (Tlili et al., 2011), that prevent oxidant damages in cells (Melo et al., 2006; Costa et al., 2012). However, fruits chemical composition may be affected by a series of factors, including its genetics, environment conditions and cultural practices (Cao et al., 2015). Within the cultural practices, the mineral nutrition has a major rule in watermelon's crop performance and quality (Barros et al., 2012; Silva et al., 2014). In these terms, the study of nutritional management, emphasizing quality and nutrients application method, is essential to check the results in production's quality. Phosphorus (P) is one of the nutrients which requires more careful management due to its low concentration in soil solution and for having scarce sources worldwide (Ashley et al., 2011). When applied in soil, P supply is limited by its strong bonding capacity when in insoluble forms (Pandey et al., 2015), however, it may be easily available for plants depending on how it is applied (Mueller et al., 2015).

In watermelon crop, P application can be applied in foundation (100% pre-planting), or in foundation and fertigation (Silva et al., 2014; Souza 2012). Pre-planting fertilization, besides the fact that may increase the initial in-solution level of P for root development, compromises the availability of nutrient throughout crop cycle. On the other side, combining pre-planting fertilization with fertigation may balance the in-solution P availability to adequate levels during plant cycle (Marouelli et al., 2015). Even though P has a large influence over growth and yield, there is not much information if it brings a great effect on fruit quality. In watermelon plants, the effects of P deficiency in reducing photosynthetic rate, stomatal conductance, and intercellular carbon concentration (Meng et al., 2014) may influence in fruit's final quality. In strawberry, P level positively correlates with in-fruit concentration of soluble solids (Cao et al., 2015). Under adequate P level, in-plant ATP levels are satisfying for sugar exportation in phloem (Rao, 1990) to fruit or leaf, and, thus, contribute to increase soluble solids in fruits. Adebooye et al. (2006) reported that P may also indirectly influence the antioxidant compounds level of fruits (total phenolic and flavonoids) through the pentose phosphate pathway. To this end, the present study tested the hypothesis of whether P levels, applied only in foundation, and in foundation + fertigation, affect physicochemical characteristics of seedless watermelon fruits hybrid 'Style'.

MATERIALS AND METHODS

The experiment was conducted from September 2013 to December 2013 in an area located in the city of Upanema (5°35'04" S, 37°12'08"W, and 123 m of altitude), state of Rio Grande do Norte, Brazil. According to Koppen climate classification, the region is BSw'h type, that is, dry and hot; presenting irregular rainfall, with average of 469.8 mm per year; temperature of 28.1°C and humidity average of 70% (CPRM, 2015). The soil in the experimental area is classified as a Cambissolo (Embrapa 2013), The characteristics of the soil as well as the water supply are shown in Table 1.

The study was carried under a completely randomized block experimental design, with four replications, arranged in a 5×2 factorial scheme. Combination of five phosphorus (P) doses and two application methods were the factorial treatments. P doses were applied only in foundation (76, 168, 275, and 397 kg ha^{-1} of P_2O_5), and in foundation + fertigation (0+50, 26+50, 118+50, 225+50, and 347+50 kg ha^{-1} of P_2O_5). Pre-planting fertilization was manually managed, in every 30 cm, with a wooden stick. Triple-super phosphate (41% of P_2O_5) applied with 100 kg ha^{-1} of Barimicro® (FTE BR12), containing 1.8% of B, 0.8% of Cu, 2.0% of Mn, 9.0% of Zn, and 4.0% of S.

Watermelon (*Citrullus lanatus,* Schrad.) used in the experiment was a seedless cultivar, hybrid 'Style'. Also, a non-commercial cultivar (diploid) was used as pollinizer. Transplanting of seedling to field was proceeded 14 days after seeding in trays with 200 cells. Spacing of 1.9×0.6 m used in field with one seedling per hole, at the proportion of two 'Style' for each pollinizer, resulting in a population of 8,872 'Style' plants per hectare. Experimental plot area formed by 16 'Style' plants, with a useful area of eight plants. Drip irrigation system was used with one dripper per plant. Depth of water applied was calculated based on daily crop water need (ET crop) using crop factor method (Allen et al. 2006). Climatic data of the period which the experiment was carried was obtained at the weather station of IFRN (Federal Institute of Rio Grande do Norte), located 40 km away from the experimental area in the city of Ipanguaçu (RN). Monthly average of climatic variables gathered: temperature of 28.7°C (±0.3); air humidity of 48.1% (±1.6); solar radiation of 24.4 kJ m² (±1.5); 00 mm of rainfall; wind at a height of 10 m of 4.5 m s^{-1} (±0.2); and reference crop evapotranspiration of 7.2 mm dia^{-1} (±0.2). In addition, an efficiency of 91% for water application was adopted based on the irrigation system. Soil moisture was monitored with tensiometers, maintaining matric potential over -30 KPa. The total depth of water applied in irrigation at the end of crop cycle was 398 mm.

Fertigation ran daily from the first day after transplanting (DAT) until the DAT 57. Fertigation system comprised by two tanks connected to water pipes independently, where one of those tanks applied fertilizer in treatments of pre-planting (foundation) fertilization, and the second one applied fertilizer in pre-planting and after-planting fertigation. Fertigation was administered based on a model developed by Paula et al. (2011), with the following fertilizers: urea, ammonium sulfate, calcium nitrate, monoammonium phosphate (MAP), potassium chloride, and magnesium sulfate. In total, 120 kg ha^{-1} of N, 90 kg ha^{-1} of K_2O, 15 kg ha^{-1} of Ca, and 15

Table 1. Characteristics of the soil¹ and water supply.

					Soil					
Clay	**Silt**	**Sand**	**pH$_{(H2O)}$**	**O.M.**	**P**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Al^{3+}**	**H+Al**
-----g kg^{-1}-----				---mg kg^{-1}---		----------------mmolc dm^{-3}----------------				
228	87	685	7.4	23.86	4	48.4	21.1	5.6	0.0	14.9
B			Cu	Fe			Mn	Zn		Pr
				--mg kg^{-1}--						
0.21			0.8	0.7			17.9	7.0		24
					Water					
E.C. **dSm^{-1}**	**pH**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**Cl^-**	**HCO_3^-**	**CO_3^{2-}**	**RAS** **$(mmol_c\ L^{-1})^{0.5}$**	
			--------------------------mmolc L^{-1}--------------------------							
0.47	7.8	2.25	0.89	0.44	2.16	1.31	4.0	0.16	1.72	

¹Chemical extrators: Mehlich-1 for P, K and Na; KCl 1N for Ca, Mg and Al; Calcium Acetate for H+Al; DTPA solution (pH=7.3) for Cu, Fe, Mn e Zn and and B available was extracted with HCl (0.05M), and soil/extractor ratio of 1:2. Pr is remaining P obtained after stir sample for one hour, in solution of $CaCl_2$ 0.01 M, with 60 mg L^{-1} of P, in ratio soil/solution of 1:10, and left to rest for 16 h and O.M is organic matter.

kg ha^{-1} of Mg were applied. Fruits were harvested in the commercial maturity (63 DAT) and transported to Laboratório de Tecnologia de Alimentos da UFERSA, where eight fruits of each treatment were evaluated the following characteristics: average fruit weight (AFW), longitudinal diameter (LD), traversal diameter (TD), pulp color [in pulp central area, measured with Minolta Chroma Meter CR-300, and results expressed in hue angle and chroma index], pulp firmness (PF) [obtained cutting fruit lengthwise, reading twice in middle area and once in basal area (opposite side of stem) on each piece, using a McCormick Penetrometer model FT 327 (12mm-diameter tip), and results expressed in Newton (N)], titratable acidity (TA) [checked via titration with NaOH 0.1 mol L^{-1} until pH equals 8.2 (IAL, 2008), and results expressed in malic acid percentage (%)], soluble solids (SS) [calculated from the juice made by homogenizing a portion of middle area of lengthwise cut of each fruit and read with a digital refractometer, with automatic temperature control, and results expressed in percentage (%)], potential of hydrogen (pH) [measured from a extracted sample using a pH meter, in buffer solution at pH 4 and 7 (AOAC 1997)], maturation index (MI) [calculated by ratio of soluble solids level (SS) and titratable acidity (TA) of pulp], total sugars content (TS) [quantified in 1.0 g of pulp using the Anthrone method and read in a spectrophotometer with absorbance at 620 nm (Yemn and Willis 1954), and results expressed in percentage (%)], reducing sugars content (RS) [measured through Somogyi-Nelson method, and results expressed in percentage (%)], total phenols content (TP) [Folin-Ciocalteau method used (Singleton et al., 1999) with a Gehaka model UV-340G spectrophotometer, and results expressed in mg GAE100 mL^{-1} of pulp], Vitamin C content (VC) [determined using the standard titration method of the Association of Official Analitical Chemists (AOAC 1984), and results expressed in mg of ascorbic acid 100 mL^{-1} of pulp]. The data was submitted through variance analysis, Tukey's HSD test with 5% of significance level and unfolding analysis using the SISVAR 5.6 software (Ferreira, 2011). The regression analysis was made using the Table Curve software (Jandel Scientific, 1991).

RESULTS AND DISCUSSION

There was isolated effect of different P doses for following traits: average fruit weight, longitudinal and transversal diameters, pulp firmness, chroma index, and hue angle (Table 1). However, the form of application did not influence physical traits of watermelons (Table 1). An increase in average fruit weight (AFW), longitudinal diameter (DL), and transversal diameter (TD) was seen in increasing doses of P up to 208, 192, and 226 kg ha^{-1} of P_2O_5, which fruits reached the maximum of 4.83 kg (AFW), 21.87 cm (LD), and 21.22 cm (TD), respectively (Figure. 1A, 1B, and 1C). P doses higher than these cited before resulted in negative effect in AFW, LD, and TD. The literature reports increment in AFW of Canary melon with phosphate fertilization, which maximum value was 42.67% higher than the AFW with no P applied (Abrêu et al., 2011). However, the ideal approach is using low doses with positive effect on quality's traits of fruits for reducing production costs, and nutrient optimization (Ashley et al. 2011). Phosphorus is the major nutrient with influence on fruit size (Mendes et al. 2010), and its significant effect over fruit's diameter and yield may be explained for its function in plants' energy system (Adebooye et al., 2006). But restricted P supply cause metabolic and physiology changes, alters plant morphology (root and leaf), and affects photoassimilates production required for plant growth (Pandey et al. 2015). Cropping with P doses up to 76 kg ha^{-1} decrease pulp firmness (PF) of fruits, but higher doses do not cause any significant variation on FP (Figure. 1D). According to adjusted equation, the highest PF (8.332 N) among cultivated fruits was achieved in absence of P, being 38.44% above the PF (6.01 N) of fruits with P dose of 76 kg ha^{-1} P_2O_5. P influences in fruiting of plants, and its lack or deficiency delays formation and maturation of fruits, what explains the higher PF of fruits from control group with no treatment. Martins et al. (2013) found a PF average of 10.63 N in 'Style' watermelon. This value was 60.96% higher than the average PF of this study. Such difference may be related to fruits' maturation stage, since this study's fruits were harvested after a longer period (78th Day After Sowing) compared to the referred authors (DAS 65). Verified an increase of chroma index

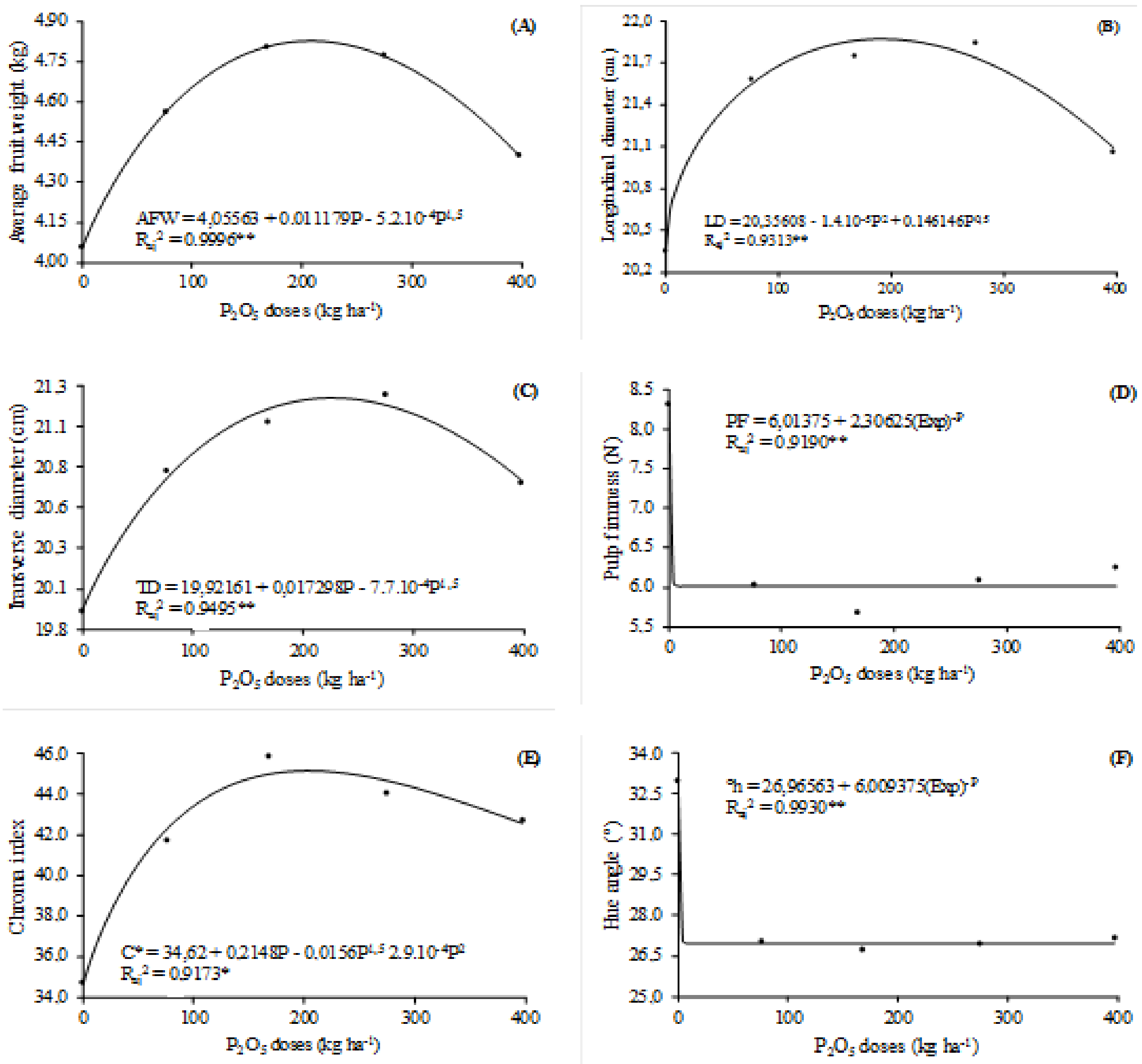

Figure 1. Average fruit weight (A), longitudinal diameter (B), transversal diameter (C), pulp firmness (D), chroma index (E) and hue angle (F) of watermelon 'Style' in different phosphorus doses.

or color intensity of fruits' pulp with increment in P, where a maximum of 45.2 for a dose of 203 kg ha^{-1} of P_2O_5 was higher than the index obtained (34.7) with no P fertilization (Figure. 1E). The higher the chroma index the clearer will be the difference between shades, turning pulp color more homogeneous (Fernandes et al., 2015). Hue angle (°h) decreased as P doses increased up to 76 kg ha^{-1}, however, from this dose, increase in P dose did not cause any variation in this characteristic. Fruits grown with 0 kg ha^{-1} of P_2O_5 showed larger °h (33.0°), a value 18.2% higher than the ones obtained (27.0°) with P dose of 76 kg ha^{-1} of P_2O_5 (Figure 1F). °h decreasing to near 0° suggests a prevalence of reddish color in watermelon pulp, which benefits its quality. In chemical characteristics of 'Style' watermelon, it verified significant interactions between P doses and form of application for titratable acidity (TA), soluble solids content (SS), pH, and total phenols content (TP) (Figure 2). Isolated effect of P dose was observed for reducing sugar content (RA), and maturation index (IM) (Figure 3). Also, isolated effect of form of application was seen in total sugars content (TS), maturation index (MI), and vitamin C content. Titratable acidity (TA) increased with increasing doses of P applied in foundation, reaching a maximum of 0.102% with a dose of 337 kg ha^{-1} of P_2O_5. From this dose, the increment in P dose caused a decrease in TA (Figure 2A). Fandi et al., (2010) reported that an increment from20 to 60 ppm of P concentration in tomato reduced in

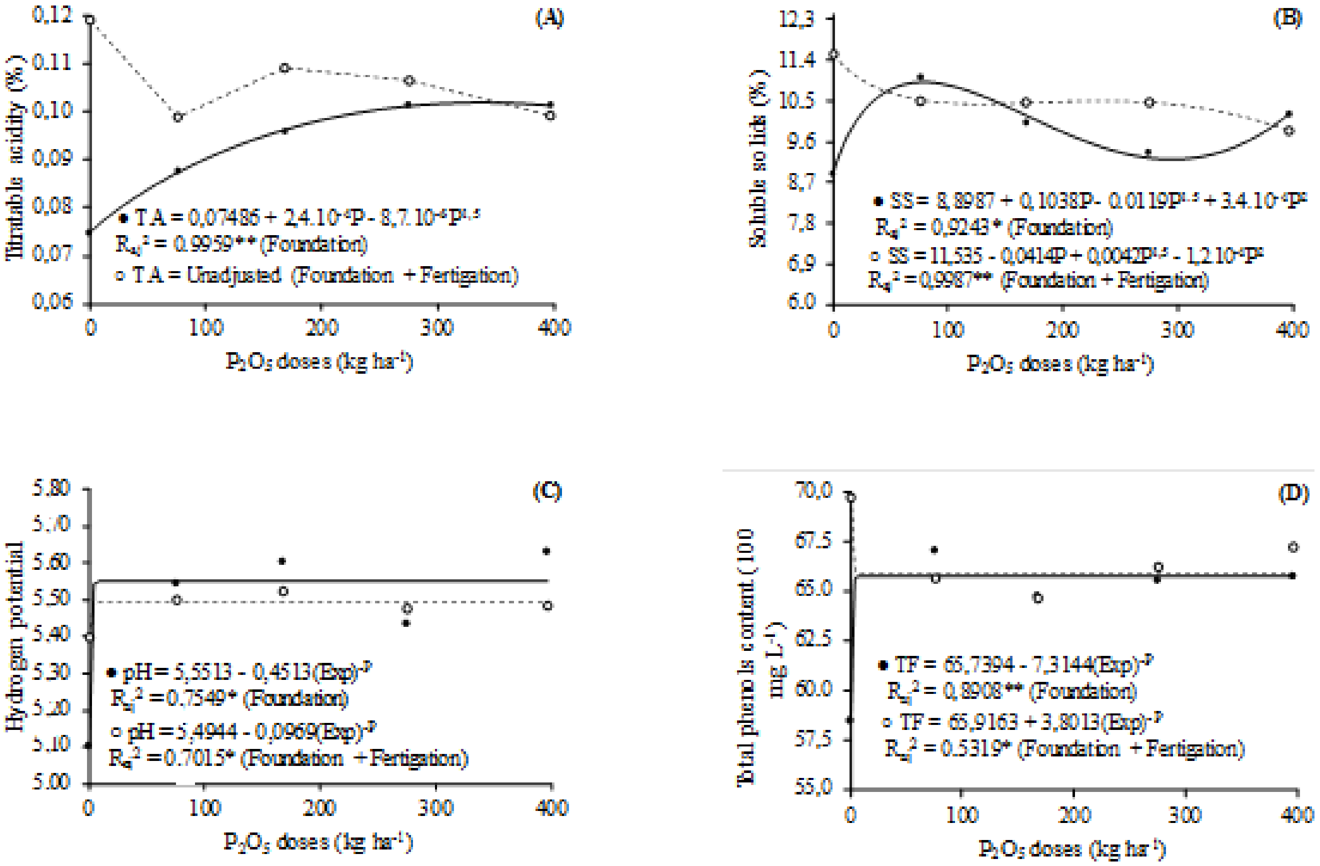

Figure 2. Titratable acidity (A), soluble solids content (B), pH (C) and total phenols content (D) of 'Style' watermelon in different phosphorus doses and application forms.

16.99% fruit acidity. On the other side, TA varied with the increase of P dose in foundation and fertigation, in which 0 kg ha^{-1} of P_2O_5 in foundation and 50 kg ha^{-1} of P_2O_5 in fertigation was the best treatment, with a value of 0.119% (Figure 2A). Watermelon is a fruit that accumulate few organic acids during its growth, and the average value at the commercial maturation stage is between 0.08 and 0.13% (Çandir et al., 2013), which is close to this study's results. An increase in P dose provided raise of the soluble solids content (SS) of 'Style' watermelon, from 8.90% without P treatment to a maximum of 10.9 and 11.5% with doses of 79 kg ha^{-1} of P_2O_5 in foundation, and without P in foundation together with 50 kg ha^{-1} of P_2O_5 in fertigation, respectively, being the fertigation P application 5.5% higher than in foundation (Figure 2B). In pineapple, there was a linear response in pulp SS for increment in P doses (Martins and Ventura 2011). The influence of P on SS is likely related to a better photosynthetic rate, and photo assimilate partitioning and transport, as Cao et al. (2015) acknowledge. The SS values obtained with combined application of P (in foundation and fertigation) were higher than the SS reported by Lima Neto et al. (2010), in different varieties of watermelon cultivated in similar soil and climate conditions, and similar results to Barros et al. (2012) in 'Crimson Sweet' watermelon (9.69 to 12.23%) cultivated with different nitrogen doses.

SS content is an important parameter of watermelon fruits quality, which ideal value must be equal or higher than 9%. Possibly, the higher average value estimated from SS obtained only with dose of 50 kg ha^{-1} of P_2O_5 in fertigation may be explained due to the balance on in soil P availability in adequate levels throughout crop cycle (Marouelli et al. 2015), making greater absorption possible for plants. It was observed that pulp pH increased in fruits cultivated with P dose up to 76 kg ha^{-1} of P_2O_5 both in foundation and foundation together with fertigation (Figure 2C). However, superior doses did not show any variation in pH in neither form. P application in foundation resulted in an increase of 8.82% in pulp pH from 5.10 (0 kg ha^{-1} of P_2O_5) to 5.55 (76 kg ha^{-1} of P_2O_5), while in fertigation increase was from 5.40 (0 + 50 kg ha^{-1} of P_2O_5) to 5.49 (26 + 50 kg ha^{-1} of P_2O_5), therefore, a slight increase of 1.67%. Similar results were reported by Adebooye et al. (2006), where they verified that increment in P doses (triple-super phosphate) up to 26.4 kg ha^{-1}, in tomato, benefited pH increase. Total phenols content (TP)

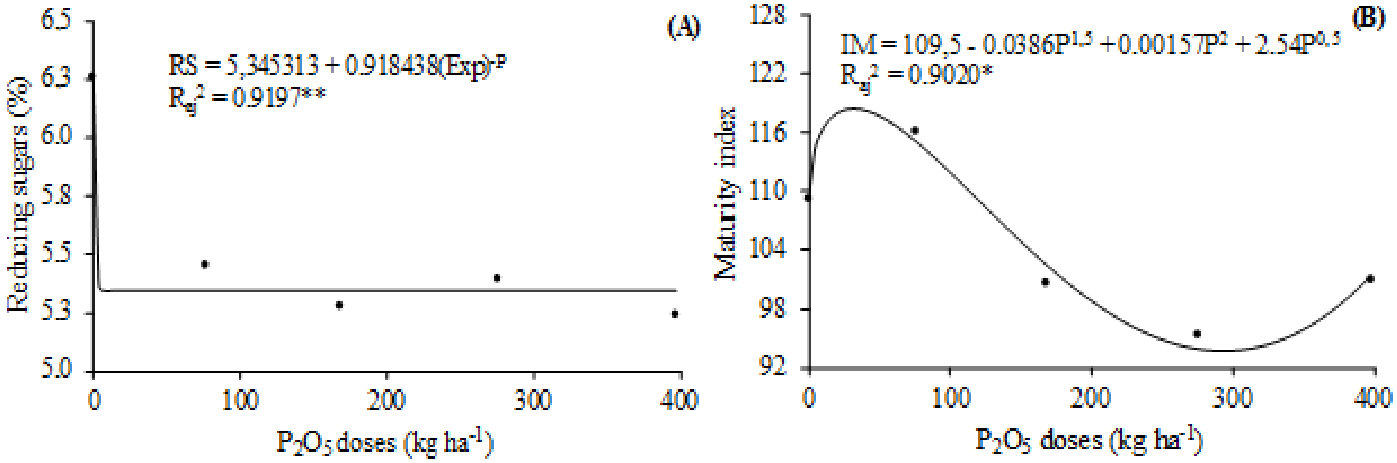

Figure 3. Reducing sugars content (A) and maturity index (B) of 'Style' watermelon in different phosphorus doses.

from fruits increased with increment in P doses in foundation up to 76 kg ha^{-1}. No significant variation was seen with increasing P supply for plant. In this form of application, levels of TP increased from 58.43 mg GAE 100 mL^{-1} (0 kg ha^{-1} of P_2O_5) to 65.74 mg GAE 100 mL^{-1} (76 kg ha^{-1} of P_2O_5) (Figure 2D). On the other side, there was adverse effect in P combined application (foundation + fertigation), which values decreased from 69.72 mg GAE 100 mL^{-1} (0 + 50 kg ha^{-1} of P_2O_5) to 65.92 mg GAE 100 mL^{-1} (26 + 50 kg ha^{-1} of P_2O_5). Levels of TP from fruits cultivated with 0 + 50 kg ha^{-1} of P_2O_5 was 5.8% higher than the highest value found in fruits cultivated with dose of 76 kg ha^{-1} of P_2O_5 in foundation. Li et al. (2002) studying P application as a mineral mixture (78.28% of P_2O_5; 14.14% of CaO; 7.58% of N) four weeks before harvest in 'Fuji' apples, verified increment in flavonoid in fruit skin. According to the authors, this behavior may be explained due to these nutrients action on increasing activity of phenylalanine-ammonia-lyase, a key enzyme in synthesis process of flavonoid compounds. In contrast, there is evidence that P deficiency in soil cause phenolic compounds accumulation in tomato and nectarine (Olivos et al., 2012; Stewart et al., 2001).

Regardless of application form, a higher concentration of reducing sugars (RS) occurred in absence of P fertilization (6.26%), and decrease when applying increasing P doses (Figure 3A). However, it is worth highlighting the low variation on levels of AR between P doses higher than 76 kg ha^{-1} of P_2O_5, which had an average of 5.35%. Levels of RS, represented as glucose and fructose, generally have larger amount in young watermelon fruits (Soteriou et al., 2014). This likely explains the higher levels of RS in fruits cultivated with no P applied, indicating delay of ripening, when compared to fruits from plants that received P fertilization. On the other side, form of application resulted in a significant difference in total sugars content (TS) of fruits (Table 2). Application of P in foundation and fertigation provided a higher increment in TS level (8.52%) than fertilization in foundation only (7.94%). This result may reflect the increase in P availability (Valentinuzzi et al., 2015) when fertigation is used (Souza, 2012), since increment in inorganic phosphate (Pi) concentration in cytosol can cause a higher transference rate of phosphate sugars in chloroplasts, via exchange of triose-P/Pi in vascular membrane. This exchange benefits the glucose formation in cytosol, which may be broken by glycolysis cycle, entering in cellular respiration, or going to saccharose synthesis (Santos et al., 2012), main sugar compound of mature fruits of watermelon (Soteriou et al., 2014). The highest averages of vitamin C (VC) and maturation index (MI) (15.45 mg 100 mL^{-1} and 109.36, respectively) were obtained with P application in foundation and fertigation, independently of P dose (Table 3). These values express superiority above 64% and 9.8%, respectively, of P applied in foundation + fertigation over the application in foundation only. The lowest averages of VC and IM, obtained with application in foundation, may be related to a lower nutrient mobility (P) caused by the presence of Calcium and clay in the experimental soil. In addition, there was effect of P doses over MI, independently of form of application, which value increased from 109.5 (0 kg ha^{-1} of P_2O_5) to a maximum value of 116.82 (17.85 kg ha^{-1} of P_2O_5), and decreasing for higher values (Figure 3B). These results were higher than the highest value of 68.78 obtained by Campagnol et al. (2016) in mini watermelon. According to the authors, higher MI indicates sweeter fruits, a desired characteristic in watermelon.

Conclusion

P doses and form of application had effect on main characteristics of quality of 'Style' watermelon (soluble solids, titratable acidity, pH, and total phenols content). However, P dose of 50 kg ha^{-1} of P_2O_5 applied only in

Table 2. Sumary of the analysis of variance for the variables average fruit weight (AFW), longitudinal diameter (LD), transverse diameter (TD), chroma index (C*), hue angle (°h), pulp firmness (PF), soluble solids content (SS), titratable acidity (TA), maturation index (MI), vitamin C (VC), total sugars content (TS), reducing sugars content (RS), total phenols content (TP), and pH of 'Style' watermelon grown under different forms of phosphorus application.

Characteristics	**SV**	**AF**	**DS**	**AFxDS**	**CV(%)**	**GA**
	DF	**1**	**4**	**5**	**----**	**---**
		F				
AVF		0.85^{ns}	2.67^{*}	0.92^{ns}	11.75	4.52
LD		1.45^{ns}	2.99^{*}	1.55^{ns}	4.74	21.32
TD		1.30^{ns}	3.24^{*}	0.98^{ns}	3.88	20.74
C*		2.14^{ns}	4.26^{**}	0.39^{ns}	13.92	41.83
ºh		2.99^{ns}	4.06^{**}	$1,97^{ns}$	13.42	28.17
PF		1.88^{ns}	11.52^{**}	1.54^{ns}	13.55	6.48
SS		10.26^{**}	2.01^{ns}	7.67^{**}	6.45	10.22
TA		20.18^{**}	1.44^{ns}	6.13^{**}	10.20	0.099
MI		6.22^{*}	3.49^{*}	2.06^{ns}	11.88	104.47
VC		$191,6^{**}$	$1,103^{ns}$	$0,654^{ns}$	11,09	12,44
TS		6.48^{*}	2.41^{ns}	0.80^{ns}	8.78	8.23
RS		0.78^{ns}	2.07^{*}	1.19^{ns}	14.92	5.52
TP		4.09^{ns}	0.63^{ns}	3.67^{*}	5.73	65.48
pH		0.08^{ns}	5.69^{**}	2.51^{ns}	2,82	5.47

SV – Source of variation; AF- Phosphorus application forms; DS- Doses; CV - Coefficient of variation; GA - General average; DF - Degree of freedom.

Table 3. Average fruit weight (AFW), longitudinal diameter (LD), transversal diameter (TD), chroma index (C *), hue angle (°h), pulp firmness (PF), vitamin C content (VC), reducing sugars content (RS), total sugars content (TS) and maturation index (MI) of 'Style' watermelon grown under different phosphorus application forms.

Fertilization	**AVF (kg)**	**LD (cm)**	**TD (cm)**	**C***	**ºh**
Foundation	4.44^{a}*	21.13^{a}	20.60^{a}	40.48^{a}	29.20^{a}
Foundation+Fertigation	4.60^{a}	21.51^{a}	20.89^{a}	43.18^{a}	27.14^{a}
HSD	0.34	0.65	0.52	3.76	2.44
General average	4.52	21.32	20.74	41.83	28.17
Fertilization	**PF (N)**	**VC (mg 100 mL^{-1})**	**RS (%)**	**TS (%)**	**MI**
Foundation	6.67^{a}	9.42^{b}	5.64^{a}	7.94^{b}	99.57^{b}
Foundation+Fertigation	6.29^{a}	15.45^{a}	5.41^{a}	8.52^{a}	109.36^{a}
HSD	0.57	0.89	0.53	0.47	8.01
General average	6.48	12.44	5.53	8.23	104.47

*Means followed by same letter do not differ by Tukey HSD test at 5% probability.

fertigation induced to significant higher values of soluble solids, titratable acidity and total phenols content in fruit. Fertilization in foundation with doses up to 337 kg ha^{-1} of P_2O_5 increased the titratable acidity. P application did not influence physical quality characteristics and reducing sugars content. However, P application in foundation together with fertigation resulted in higher accumulation of vitamin C, total sugars content, and maturation index of fruits. Cultivation with P doses up to 76 kg ha^{-1} of P_2O_5 decreased pulp firmness, but higher doses caused no variation in those characteristics. Average fruit weight increased with P doses up to 208 kg ha^{-1} of P_2O_5. This way, at the present study conditions, we could evidence that low doses of P for 'Style' watermelon cultivation, and combined application in foundation and fertigation, provided improvement in fruit' main quality characteristics.

Conflict of interests

The authors have not declared any conflict of interests.

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Crambe performance depending on the potassium doses and cultivation in red latosol

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Nowadays, the society is seeking renewable energy sources that will replace in a sustainable way, fossil fuels. A source of energy that has stood out with great energetic potential showing itself to be promising in the world is biodiesel. Among several alternatives, the crop, Crambe (*Crambe abyssinica* Hochst) stands out as an oilseed species plant that belongs to the *Brassicaceae* family. This culture as a source of feedstock for biodiesel production was studied for its high yield of oil production, with about 38% of its grains. In order to get more information on the development of the crop in west of Paraná, it is necessary to develop studies on the response of this crop to fertilization. This study aimed to evaluate the crambe response to doses of potassium (K) grown in Oxisol in west of Paraná. The experimental design was of randomized blocks and the treatments consisted of doses of K (0, 40, 80, 120 and 160 kg ha^{-1} of K_2O), with four replicates. For the assessments, a week preceding the harvest, five plants were collected per plot to measure the morphological features and yield components: plant height, average number of racemes per plant, average length of racemes per plant, number of fruits per plant, and fruit number per raceme and productivity. The results indicate that the soil Oxisol of Toledo has good availability of K. Because of this, significant increments in K_2O doses on morphological characteristics and yield components have not been verified. The K_2O doses did not promote increments on crambe production components.

Key words: Biodiesel, development, *Crambe abyssinica* Hochst, feedstock.

INTRODUCTION

Crambe crop (*Crambe abyssinica* Hochst) is an oleaginous plant that belongs to the *Brassicaceae* family, having its place of origin in the Mediterranean region and with occurrence reports of some species in Ethiopia (Weiss, 2000). It is considered as a winter oilseed, having good resistance to drought and short cycle, ranging from

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Table 1. Chemical and texture attributes of latosol collected in case depth of 0 to 0.2 m Toledo- PR, 2015.

[1]pH	C	P	Ca^{2+}	Mg^{2+}	K^{+}	Al	H+Al
	g dm^{-3}	mg dm^{-3}	--------------$cmol_c dm^{-3}$-------------------				
5.80	19.09	19.09	5.95	2.06	0.54	0.08	6.21
	SB	CTC	V	Silt	Clay	Sand	
	$cmol_c dm^{-3}$		%	------------g kg^{-1}------------			
	8.55	14.76	57.92	180	720	100	

P, K^+ – Mehlich-1; Ca^{2+}, Mg^{2+} e Al^{3+} – KCl; C – Walkey Black; pH – Calcium chloride; H + Al – buffer SMP (Lana et al., 2010).

90 to 100 days. Crambe is a very resistant crop to pests and diseases, with 26-38% of oil content in dry mass (Machado et al., 2007).

As it is a suitable crop for cultivation in the autumn/winter period, crambe can be a good option for the off-season harvest, due to its tolerance to low temperatures, with high oil content, low production cost, besides its oil been inedible, which makes it a crop with good characteristics for the biodiesel production (EMBRAPA, 2006). Biodiesel has as its main sources of oil, peanut oil, cotton, canola, palm oil, jatropha, crambe, castor bean and soybean, in addition to beef tallow, chicken fat and frying oils already used (Epstein, 2004; Mourad, 2006).

For Rudolf and Wang (2012), there are three reasons why the crambe is a unique oilseed crop: between the brassicas, this species is the one that contains the highest quantity of erucic acid, which is of great industrial interest. It has the highest yield, as compared to rapeseed, requiring however less cultivation efforts; besides not spontaneously hybridized with other brassicas.

Crambe's productivity in Brazil reaches 1000-1500 kg ha^{-1} (Baez 2007; Pitol et al., 2008), reaching in the fields of Assis Gurgacz University and Mato Grosso do Sul Foundation 2300 kg ha^{-1} (Mai Neto, 2009). In Europe and in the United States, there have been productivities higher than 3000 kg ha^{-1} (Pitol et al., 2008).

Regarding the nutritional needs of the crop, the root system of crambe is deep and, bearing this in mind, it becomes very sensitive to toxicity of aluminum, requiring a very well corrected soil profile. The production of crambe is impaired by the presence of exchangeable aluminum in the soil and also by low contents of calcium and magnesium. The correction of the soil should be carried out so that the pH is high, considering ideal range of pH for crambe crop to be between 5.8 and 6.2 (Broch and Roscoe, 2010).

Despite having good rusticity, this plant requires sowing in fertile, deep and corrected soils. Crambe is a crop that considered a recycler of soil nutrients, and with great potential for the exploitation of waste-fertilization of the preceding crops. In experiments implemented by the MS foundation, crambe had no significant responses to NPK fertilization at planting when the soil was corrected and with good levels of P and K (Pitol et al., 2008).

According to Carlsson (2009), for the improvement of crambe culture and oil producer, studies related to proper planting time in different states, fertilization, density, and loss of yield at harvest are of utmost importance.

In southern Brazil, this culture is beginning to be cultivated, but little is known about the conditions that may limit its production. This study aims to evaluate the production of crambe on different doses of potassium, seeking a better specification of the fertilizer thereof.

MATERIALS AND METHODS

This study was conducted in the experimental area of the Catholic University of Paraná, *campus* Toledo, located in the following geographic coordinates: latitude 24° 43' 70,35"S and longitude 53° 46' 04,16"W, 551 m altitude. The soil in the area is classified as Oxisoil, clayey in texture (EMBRAPA, 2006), and the particle size composition of the soil is shown in Table 1.

The experimental design adopted was randomized blocks with four replicate, with chemical analysis are showing the treatments constituted by the K doses (0, 40, 80, 120 and 160 kg ha^{-1} of K_2O). Potassium chloride, 60% K_2O as was used as K source and crambe cultivar FMS Brilhante, with plant density was adjusted by thinning for 100 plants m^2, distance between rows was 0.17 m within 24 m^2 plots (4 x 6 m).

The base fertilization was 40 kg ha^{-1} of N and 100 kg ha^{-1} of P_2O_5. For coverage, it was added in the form of sulphate of ammonia 160 kg ha^{-1} of N, totaling 200 kg $ha^{-1}$of N. The base fertilization of crambe was done on April 26, 2015. This fertilization of plots was carried out with different doses of KCl held by haul, then the sowing of cultivar Brilhante FMS was done with spacing of 0.17 (m) between rows and the germination.

With crambe plants in stage V4 (four leaves expanded), weeding was carried out and after twenty days after emergence, cover fertilization with ammonium sulfate was also done in the amount of 160 kg ha^{-1}.

Variables analyzed were plant height (PH), average length of racemes per plant (ALRP), number of racemes per plant (NRP), number of fruits per raceme (NFR), fruit number per plant (FNP) and productivity.

To quantify the productivity, in kg ha^{-1}, on each plot, were we eliminated the first and the last line, totalizing 18 m^2. Data were submitted for analysis of variance and when significant, polynomial regression analysis was carried out using the software SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

Doses of K did not increase ($p > 0.05$) the morphological components and production of cultivated crambe in the 2015 harvest, as shown in Table 2. To determine the dry matter production and accumulation of macronutrients in the of crambe plants at different stages of growth and development, Mauad et al. (2013) conducted an experiment assessing mineral absorption of nutrients, collecting air samples of the plants at 14, 28, 42, 56, 70

Table 2. Analysis of variance for plant height (PH), number of racemes per plant (NRP), average length of racemes per plant (ALRP), number of fruits per raceme (NFR), fruit number per plant (FNP) and productivity in relation to K doses evaluated for the crambe crop grown in Oxisol of Toledo, Paraná.

V.S	D.F.	M.S.					
		PH	NRP	ALRP	NFR	FNP	Productivity
Block	3	0.032*	1.232*	0.0002*	424.39*	122907.5*	92626.9*
Dose	4	0.005^{ns}	1.307^{ns}	0.0004^{ns}	143.58^{ns}	36749.5^{ns}	30859.5^{ns}
Error	12	0.008	1.560	0.0011	82.23	27040.1	48983.5
V.C.		7.02	7.93	8.53	15.19	17.57	20.54
Average		124.9	15.76	0.39	59	936.1	1077.8

*Significant at 5% of probability (0.01 = < p < 0.05); ^{ns} non-significant (p >= 0.05).

and 84 days after emergence. The authors showed that the K builds up leaves, stems and branches rapidly, with the beginning of flowering; there is considerable drop in the accumulated K and K have high mobility in plants at any concentration level, either within the cell, in plant tissue, the xylem or phloem.

Therefore, it is noted that the K increase in the fertilization had no influence on the crambe production components. On the other hand, there was a reduction of pH in function of K doses (Figure 1A). The mean value observed was 1.25 m. In results obtained by Pitol et al. (2010), crambe plants in a seed production field reached an average height of 0.80 m. In addition, Freitas (2010) in an experiment carried out in Dourados in Mato Grosso do Sul State, Brazil, obtained 1.02 m of plant height in the 2008 harvest.

Although not fertilized with nitrogen culture, the area where the experiment was performed had a content of 19.09 of C (Table 1) which provides N mineralization to the crop, and, this nutrient has high mobility in the plant (Marschner, 1995), which is reflected in vegetative growth.

With regard to the NRP, no significant differences (p> 0.05) were found between doses of K (Figure 1B). According to Mauad et al. (2013), evaluation of racemes should be performed at 75 DAE depending on the later gains of dry matter, the maximum accumulation of nutrients in these structures due to translocation of nutrients for the formation of grains after flowering and early senescence of plants.

In this research work, the crambe changes were made in one crambe crop, to simulate production performance parameters achieved in the west of Paraná State, Brazil, where producers use soybean crop rotation system in summer and corn second crop in winter, with rare species for crop rotation (Alves Neto et al., 2016). As for ALRP, no significant differences were observed (p> 0.05) between the dose of K, the mean value was 38.25 cm (Figure 2A).

However, it is noteworthy that in the field, there was greater stem diameter for plants that received fertilization with K. This stem thickening reflects the higher photosynthetic efficiency of crambe plants; however, the size of the plants did not increase. Pitol et al. (2010), when assessing the doses of 0, 100, 200, 300 kg ha^{-1} of NPK 07-24-24 applied at sowing of crambe in Maracaju in Mato Grosso do Sul, found no statistical differences between the results. On the contrary, Bertozzo et al. (2011) noted an increase in crambe plant growth and the same was linear.

As for the NFR, no significant differences (p>0.05) were found; however, the highest values were found in the dose 160 kg ha^{-1} K_2O, as shown in Figure 2B. In the culture of canola, Degenhardt and Kondra (1981) found that the distribution of plants in an area can transform its vegetative and reproductive development.

According to Silva et al. (1983), these changes are related to competition between individuals, as a result of the variation of spacing between rows and the sowing density which can reduce the number and weight of siliques per plant.

Regarding the NFP (Figure 3A), a better result was observed with the dose of 80 kg ha K_2O. A justification for these results would be lower translocation of K from plants to grains. Cordeiro et al. (1999) found that the culture of canola, removes good amount of K but translocates very little to the seeds, requiring less potassium fertilizer than other crops.

Another finding can be attributed to phosphorus and potassium contents from soil of this research that are at very high levels, and so, the number of siliques per plant did not respond to doses of K. For productivity, although some treatments showed good production, significant interferences of the K_2O doses were not observed (p> 0.05) (Figure 3B). In this study, it was observed that the average yield was 934 kg ha^{-1}. Pitol (2008) reported that culture has the potential to produce between 1,000 and 1,500 kg ha^{-1}.

In one of the few studies that address the issue in Brazilian conditions, Freitas (2010) found that the K_2O doses ranging from 0 to 60 kg ha^{-1} in an Clayey Red Latosol, savanna phase, with content above 250 mg dm^{-}

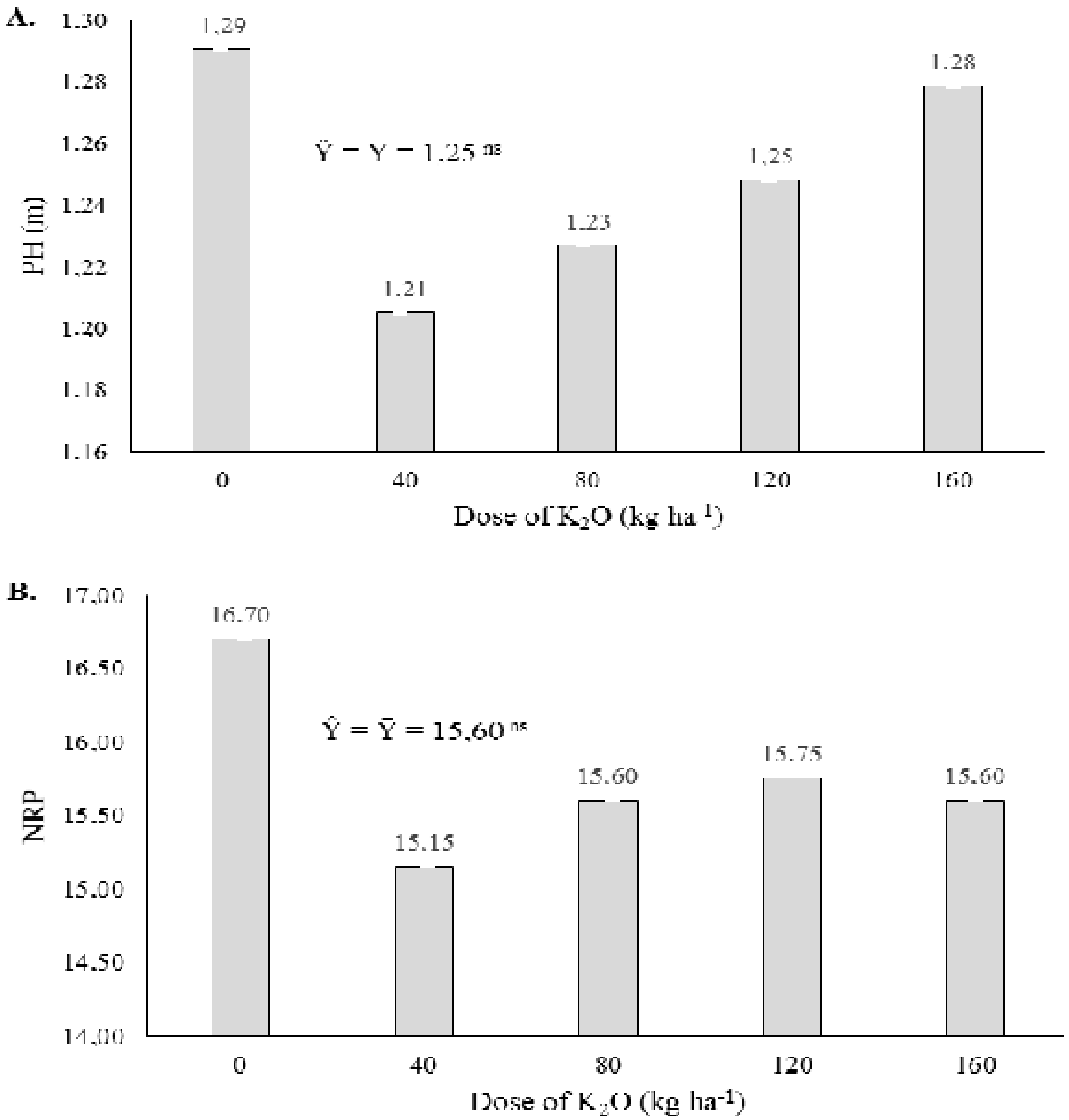

Figure 1. Average results for plant height (A) and number of racemes per plant (B) under different doses of K_2O applied in the crambe crop cultivated in Oxisol typical of Toledo, PR.

^{3}de K, did not show increases in grain yield in the harvests of 2008 and 2009, attributing this result to the high availability of K in the soil.

However, in crops similar to crambeas canola, Avila et al. (2004) found that the application of doses between 50 and 70 kg ha^{-1} of K_2O made canola productivity to remain at appropriate levels. Significant increases in productivity of canola grains and/or grapes with potassium fertilization have been narrated in many countries like Pakistan (Khan, 2004). Rossetto et al. (1998) in soil with 35 mg dm^{-3} of K, highlighted that potassium fertilization did not favor the growth of plants and canola productivity, but resulted in higher retention of siliques in late harvests.

With regard to the harvest of the crop, it was found that crambe has a specific mass that is very low, which requires attention during harvest so that there is no waste, causing loss of production.

Conclusion

The oxisol from this paper shows a good availability of K

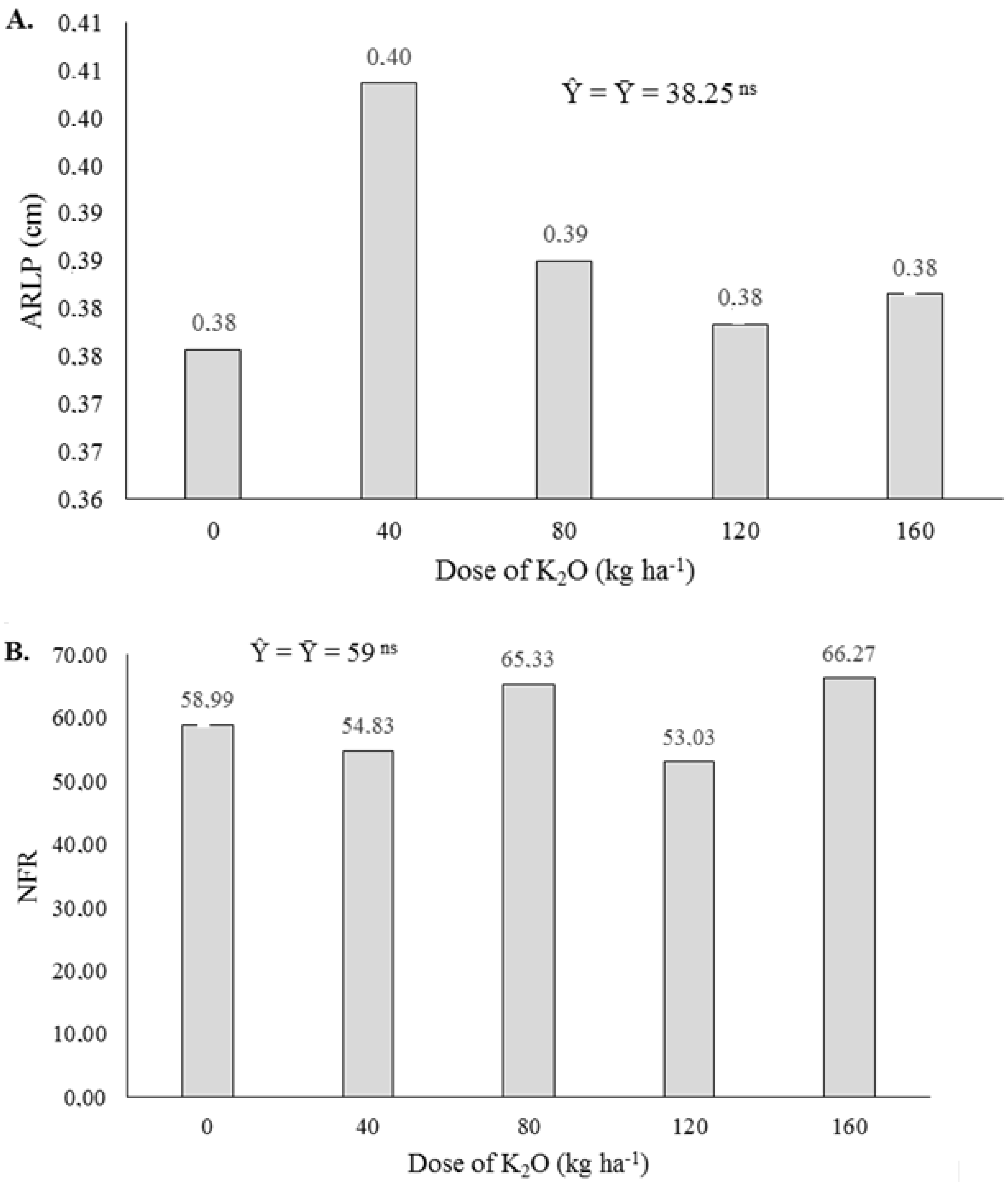

Figure 2. Average results for average length of racemes per plant (A) and number of racemes per plant (B) depending on the K_2O doses applied in the crambe culture cultivated in Oxisol typical of Toledo, PR.

and, because of this, significant increments of the K_2O doses on the morphological characteristics and in the crambe production components was not found.

Besides this, the cultivar FMS Brilhante showed great adaptability and development in the soil of Toledo, in the west of Paraná.

Conflict of interests

The authors have not declared any conflict of interest

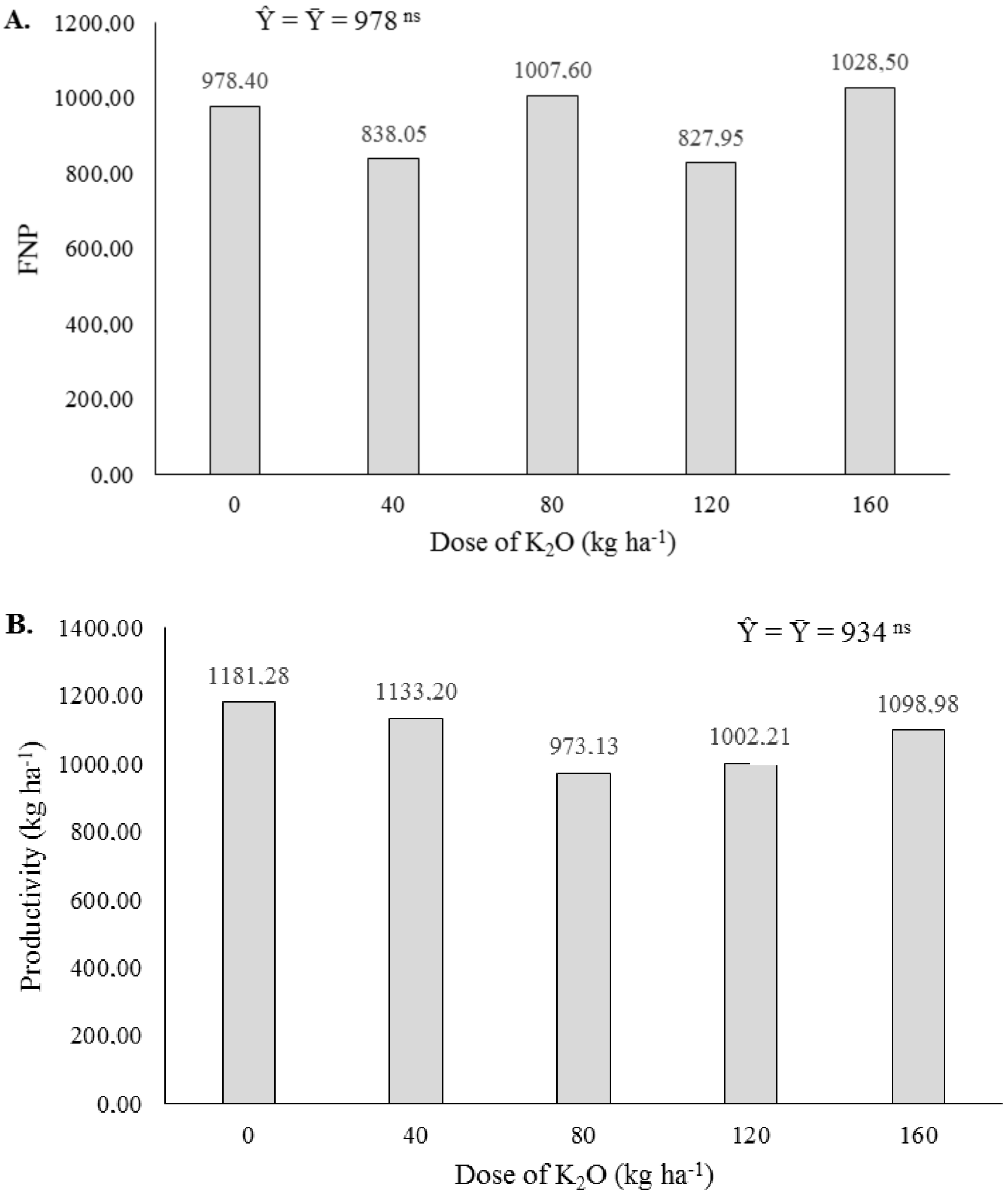

Figure 3. Average results for fruit number per plant (A) and productivity (B) depending on the K_2O doses applied in the crambe crop grown in Oxisol typical of Toledo, PR.

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Technical efficiency of beef cattle production technologies in Nigeria: A stochastic frontier analysis

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The paper investigated the determinants of beef cattle production and technical efficiency of beef cattle farmers using stochastic frontier production function which incorporates a model of inefficiency effects. A multi-stage random sampling procedure was employed for the selection of 360 respondents comprising 97 nomads, 208 agro-pastoralists and 55 ranchers across the 6 major producing states in Nigeria. The inefficiency effects are assumed to be functions of education of farmers, beef cattle farming experience, access to credit sources and farmers' membership of cooperative societies. Empirical results indicate that significant increase recorded in output of beef cattle in the country could be traced mainly to the critical inputs. The estimated average technical efficiencies for the three groups were 0.59, 0.69 and 0.83 for the nomadic pastoralists, agro-pastoralists and ranchers, which indicated that there is still much opportunity for increased efficiency given the present state of technology. The need to develop some low cost labour saving technologies to ease labour constraints on farms was emphasized.

Key words: Beef cattle, production technologies, efficiency, stochastic frontier analysis, Nigeria.

INTRODUCTION

The livestock sub-sector (LSS) has always been an important component of Nigeria's economy. In addition to its contribution to the Gross Domestic Products (GDP) of the country, it contributes substantially also to the supply of animal protein (FDLPCS, 2013). By its population and capacity for animal production, with 25% of livestock herds in the sub-region, Nigeria is by far the leading livestock producer in Central and West Africa (Grain de sel, 2012). Based on the limited empirical and policy-focused enquiries, huge endowment of natural resources, public expenditure and private investment on cattle production in Nigeria, beef cattle was selected as representative of livestock for the study. Cattle are indeed the most predominant and highly valued livestock in Nigeria but there is a documented report on a decline in beef cattle production especially, in developing countries; a wide gap exists between the level of local production and national needs and demand. The average demand for beef in Nigeria from 2006 to 2015 stood at 286 MT whereas the supply was 235 MT for the same period, a

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deficit of 51 MT (OECD-FAO, 2015).

It is obvious that Nigeria, with a population of over 160 million people requires several heads of cattle to satisfy its demand for cattle and cattle products. Again with a population growth rate nearing 2.8% per year, the country's own domestic production is by far from being able to meet demand (Grain de sel, 2012). In the bid to address the demand supply gap, governments at various times have come up with policies and programmes which have been observed to be inconsistent. These erratic policies reflect the dilemma of securing cheap beef for consumers and fair price for producers. Notwithstanding the various policy measures, domestic beef cattle production has not increased sufficiently to meet the increased demand (Nwigwe et al., 2015). Thus, these fluctuations in policy and limited capacity of the Nigerian beef sector to match the domestic demand have led the country to expend huge amount of foreign exchange on the importation of beef into the country. The limited capacity of the Nigerian beef sector to meet the domestic demand has raised a number of pertinent questions both in policy circle and among researchers. For example, what are the factors explaining why domestic beef production lag behind the demand for the product in Nigeria? Central to this explanation is the issue of efficiency of the beef cattle farmers in the use of resources.

Some researchers (Loevinsohn et al., 2012; Beshir et al., 2012; Diiro, 2013) opined that attention to productivity gains arising from a more efficient use of existing technology is justified. They argued that since the presence of shortfalls in efficiency means that output can be increased without requiring additional conventional inputs and without the need for new technology, empirical measures of efficiency are therefore necessary in order to determine the magnitude of the gain that could be obtained by improving the performance of a production system with a given technology. Mor and Sharma (2012) and Challa (2013) also argued that an important policy implication stemming from significant levels of inefficiency is that it might be more cost effective to achieve short-run increases in farm output, and thus income, by concentrating on improving efficiency rather than on the introduction of new technologies.

At present, there is no comprehensive and up to date information as regards the level of resource use efficiencies of the beef cattle farmers, given the existing technologies. The few available ones were either system based or location specific. Most of these studies focused mainly on the profitability of the enterprise without an in depth inquiry into efficiencies of farmers and factors that determine their level of efficiency. Thus the main focus of this study is to determine the levels of technical efficiency of beef cattle farmers and explain those factors that determine their levels of efficiency. Given the fact that a number of beef cattle development programmes such as improvement in the breeding and feeding methods as well as hybrid development have been implemented to boost the beef sector in Nigeria, the study has been designed to cover the identified three major beef cattle production systems in Nigeria viz, nomadic pastoralism, agropastoralism and ranching. Specifically, the objectives of the study were:

i) to analyze input use and socioeconomic characteristics of the farmers;
ii) to determine the technical efficiency of the beef cattle farmers and establish the differentials in technical efficiency between the three group of farmers;
iii) to examine the factors that determine the level of technical efficiency of the farmers.

Nomadic pastoralists (also referred to as nomads) typically have temporary abodes and migrate seasonally with cattle and other livestock in search for pasture and water. They are less commercialized, but derive a relatively large share of their livelihood from cattle and other livestock. In contrast, the agropastoralists are sedentary; within this system, livestock rearing and crop production are practiced interdependently, where livestock is grazed on harvested fields and animal manure is applied as crop fertilizer (Otieno et al*.,* 2012). In comparison to the traditional pastoralist system where herders go in search of pasture and water during dry seasons, sedentary agro-pastoralists face additional challenges from land pressure and limited pastures for their cattle. However, agro-pastoralist system is more commercialized than the nomadic system. Ranches are purely commercialized livestock enterprises and may also grow a few crops for use as on-fodder or for sale. They mainly use controlled grazing on their private land, and purchased supplementary feeds, in contrast to both the nomads and agropastoralists that generally depend on open grazing, with limited use of purchased feeds. Investigating the TE of various beef cattle production systems in Nigeria should provide insights on how to better integrate livestock development into the national and economic agenda, as well as guidance to farmers on resource allocation.

There is an extensive literature on TE analysis on crop, dairy and mixed crop-livestock enterprises. However, published research on TE of beef cattle is very limited; exceptions include Otieno et al*.* (2012), Priyanti et al*.* (2012), Permani (2013), Mlote et al*.* (2013), Isyanto et al*.* (2013), Setianto et al*.* (2014), Nwigwe et al*. (*2015), Gayatri and Vaarst (2015), Cillero et al*.* (2016) and Gayatri et al*.* (2016). In Nigeria, where the livestock sector contributes about 31% of agricultural output (NBS, 2013; ABS, 2013), there are few studies on livestock systems, including beef cattle (Girei et al*.,* 2013; Mamza et al*.,* 2014; Nwigwe et al*.,* 201 6) but none of the studies except Nwigwe et al*.* (2015) emphasized on efficiency of the production systems. The studies undertaken on TE in Nigeria mainly focused on crops (Anyiro et al*.,* 2013;

Ohen et al*.,* 2014; Olufemi et al*.,* 2015; Obike et al., 2016; Agboola, 2016; Osanyinlusi and Adenegan, 2016; Addison et al., 2016); to mention a few.

The rest of the paper is organized as follows: conceptual framework was first presented, followed by a description of the data source, variable measurements and empirical estimations. Results are thereafter presented, discussed and the study concluded.

CONCEPTUAL FRAMEWORK

Technical efficiency (TE) is defined as the ability of a firm to produce a maximum output from a given level of inputs, or achieve a certain output threshold using a minimum quantity of inputs, under a given technology. In other words, a measure of technical efficiency indicates the extent to which a farm could produce additional output without changing the levels of inputs used if it were to operate on the production frontier, which is determined by the best-practice farms. The level of technical efficiency of a particular farm is therefore characterized by the relationship between observed production and some ideal or potential production. The measurement of firm specific technical efficiency is based upon deviations of observed output from the best production or efficient production frontier. If a farmer's actual production point lies on the frontier, it is perfectly efficient. If it lies below the frontier then it is technically inefficient, with the ratio of the actual to the potential production defining the level of efficiency of the individual farmer.

Farrell's definition of technical efficiency led to the development of method for estimating the relative technical efficiency of farmers. The common feature of these estimation techniques is that information is extracted from extreme observations from a body of data to determine the best practice production frontier. From this the relative measure of technical efficiency for the individual farmer can be derived. There are two methods widely used in the literature to estimate technical efficiency. The first one is an econometric approach which aims to develop stochastic frontier models based on the deterministic parameter frontier of Aigner and Chu. The second is Data Envelopment Analysis (DEA), which uses a non-parametric approach or mathematically programming method that is useful for multiple-input and multiple-output production technologies.

The econometric approach is stochastic and parametric. It has the ability to separate the effects of noise from the effects of inefficiency and confound the effects of misspecification of functional form (of both technology and inefficiency) with inefficiency, but generates good results only for single output and multiple inputs. On the contrary, the mathematical programming approach is not stochastic and not parametric. It cannot separate the effects of noise and inefficiency during the calculation of technical efficiency, and less sensitive to the type of specification error, but could be useful to apply to farms with multiple-inputs and multiple-outputs production. Since beef cattle production in Nigeria is an example of single output and multiple-input production, this study focuses on the use of an econometric approach for measuring technical efficiency based on the production frontier model. A production frontier model can be written as:

$$\gamma_i = f(X_{ij}\ ; \beta)\ +\ \varepsilon_i \qquad (1)$$

where γ_i is output of the i farm, X_{ij} is a vector of inputs used by farm $i,$ and ε_i is a "composed" error term. The error term ε_i is equal to v_i - u_i. The term v_i is a two-sided $(-\infty < v_i < \infty)$ normally distributed random error $(v \sim N[0, \sigma_v^2])$ that represents the stochastic effects outside the farmer's control (e.g. weather, natural disaster, and luck), measurement errors, and other statistical noise. The term u_i is a one-sided $(u_i \geq 0)$ efficiency component that represents the technical inefficiency of farm. The distribution of term ui can be half-normal, exponential, or gamma. The assumption of term ui in the study is a half-normal distribution $(u \sim N[0, \sigma_u^2]$ mainly used in the other studies. The two components vi and ui are also assumed to be independent of each other.

Equation 1 estimated by the maximum likelihood analysis creates consistent estimators for β, λ and σ, where β is a vector of unknown parameters, λ = ${}^{\sigma u}/_{\sigma v}$, and σ^2 = σ_u^2 + σ_v^2. The technical inefficiency of individual farms can be estimated by using the conditional distribution of ui given the fitted values of ε and the respective parameters. If we assume that vi and ui are independent of each other, the conditional mean of ui given ε is identified by:

$$E\left(\frac{ui}{\varepsilon i}\right) = \sigma^*[\frac{f^{*(\varepsilon_i\,\lambda/\sigma)}}{I - F^*(\varepsilon_i\,\lambda/\sigma} - \frac{\varepsilon_i\,\lambda}{\sigma}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where σ^{*2} = $\sigma_u^2\ \sigma_v^2$ / σ^2, f^* is the standard normal density function, and F^* is the distribution function, both functions being estimated at $\varepsilon\lambda/\sigma$.

With the assumption of half-normal model, a simple z-test was used for examining the existence of technical inefficiency, the null and alternative hypotheses are H_0: λ $= 0$ and H_1: $\lambda > 0$. The test statistic is:

$$Z = \frac{\lambda}{S_e(\lambda)}\ \sim N\ (0,1,2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where λ is the maximum likelihood estimator of λ and $se\ (\lambda)$ is the estimator of its standard error. The technical efficiency of the farms were estimated by using the following equation:

$$TE_i = \exp(-\mathring{u}) = \exp(\ -E({}^{ui}/_{\varepsilon i}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

TE_i is greater than zero and less than 1. The maximum

Table 1. Average input use, output and socio-economic characteristics of farmers by technology per hectare.

Variable input	Nomadic system	Agropastoral system	Ranching system
Yield (Kg/ha)	16,511	8,203	44,813
Farm size (Ha)	1.64	3.26	4.86
Herd size in number	49	42	53
Forage (Kg)	184.14	194.73	245.18
Feed/supplements (Kg)	21	36	64
Medicine/drugs (vials)	142	209	805
Family labour (Persons days)	204	198	102
Hired labour (Persons days)	621	273	1724
Household size (number)	11	11	11
Age in years	47	47	44
Years of experience	21	20	17

Source: Field Survey (2014).

likelihood estimates of the parameters of function (1) and the farm-level TE in (4) formular are achieved by using STATA version 11 software.

Several approaches are used to analyze the determinants of technical efficiency from stochastic production frontier functions. The first followed two-step procedure in which the frontier production function is first estimated to determine technical efficiency indicators while the indicators thus obtained are regressed against a set of explanatory variables which are usually firms' specific characteristics (Otieno et al*.,* 2012; Olufemi et al*.,* 2015). The major drawback in this approach is the fact that it violates the assumption of the error term. In the stochastic frontier model, the error term (the inefficiency effects) are assumed to be identically independently distributed.

In the second step however, the technical efficiency indicators obtained are assumed to depend on certain number of factors specific to the firm, which implies that the inefficiency effects are not identically distributed. This major drawback led to the development of more consistent approach which modeled inefficiency effects as an explicit function of certain functions specific to the firm, and all the parameters are estimated in one step, using maximum likelihood procedure (Mor and Sharma, 2012; Anyiro et al*.,* 2013; Ohen et al*.,* 2014; Watcharasakonpong and Thiengburanathum, 2016). The maximum likelihood procedure was therefore adopted in the present study due to its consistency.

METHODOLOGY

Data source

The study used survey data from six states (Oyo, Ebonyi, Delta, Adamawa, Sokoto and Niger) that are representative of the three beef cattle production systems in Nigeria, namely nomadic pastoralism, agropastoralism and ranching. Nigeria is found in the tropics, where the climate is seasonally damp and very humid. The natural vegetative zones that exist in the country are governed by the combined effects of temperature, humidity, rainfall and particularly, the variations that occur in the rainfall. The humid tropical forest zone of the south that has longer rains is capable of supporting crop production while the northern part of the country representing about 80% of the vegetative zones experience lower rainfall and shorter rainy season and they make up the savannah land. The savannah land forms an excellent natural habitat for a large number of grazing livestock such as cattle. Nigeria's agro-ecological zones can be classified into: mangrove forest and coastal vegetation; forest zone; derived guinea savannah; guinea savannah zone, sudan savannah (short grass savannah); sahel savannah (marginal savannah) and montane savannah. The areas sampled in the study represent different agro-ecological zones, but are contiguous, hence logistically more accessible.

A multi-stage sampling technique was used for the study. In each of the six states, 2 Local Government Areas (LGAs) were selected. Within the 2 LGAs, 4 smaller units (villages) were randomly selected from the list of all the villages in the LGAs, taking into account the general distribution of cattle in the study area. Subsequent stages involved a random selection of a sample of 5 locations. The primary sampling units for the survey were therefore 20 locations in each state. In each of the location, a random sample of respondents was drawn from the list of farmers; in total, 360 farmers including 55 ranchers, 97 nomads and 208 agropastoralists were interviewed. A structured questionnaire was used to collect data on resource inputs and output in beef cattle production, cultural practices of the farmers and their socioeconomic characteristics like age, education, household size etc.

With the assistance of well experienced extension officers, who were trained prior to the survey, the questionnaire was piloted, revised and then administered through face-to-face interviews of farmers between October 2013 and March, 2014. Due to incompleteness of some of the questionnaire, a total of 339 respondents were finally used for the analysis (39 ranchers, 92 nomads and 208 agro-pastoralists). A summary of the variables which were used in the analysis is presented in Table 1.

Variable measurement

Beef output was considered as the dependent variable in the study. Due to measurement difficulties, previous studies have used proxy variables such as physical weights of cattle; however, such data were not available in the present study. This study therefore followed the revenue approach employed by Otieno et al*.* (2012).

The model is hereby expressed as:

$$Q_{n(k)} = \frac{\sum_r^R yp}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where $Q_{n(k)}$ is the annual value of beef cattle output in the n^{th} farm in the k^{th} production system (measured in Nigerian Naira; N) r denotes any of the three form of cattle output considered (e.g. current stock, sales or uses for other purposes in the past twelve-month period); y is the number of beef cattle equivalents[1] (conversion factor); p is the current price of existing stock or average price for beef cattle sold/used during the past twelve months; and t is the average maturity period for beef cattle in Nigeria, which is four years (FDLPCS, 2013). The output prices used were average market prices; this possibly controls for differences associated with various market types and ensures that TE measures are attributable to farmers' managerial abilities.

The main inputs used for the study included herd size (proxy for capital in the classical production), feeds, medicine/drugs, labour, land and other inputs. The cattle herd size was computed as the average number of cattle kept in the past twelve months, adjusted with the relevant conversion factors. In order to capture the approximate share of feeds from different sources in each production system, the quantities of forage (or on-farm) feeds were first adjusted with the average annual number of dry and wet months, respectively, in each state following ABS (2014). Medicine/drugs were measured in vials. Due to measurement difficulties, the local herbs used especially by the Fulani in the treatment of their cattle were not considered.

Labour costs comprised both paid and unpaid labour; the latter valued using the average minimum farm wage in a particular agro-ecological zone. The labour costs were adjusted with the share of cattle income in household income. Land was measured as farm size (adjusted with the share of cattle income in household income). However, it was found to be highly correlated with feeds in agro-pastoralism. Further, it was difficult to establish owner-occupancy on land with respect to cattle production for nomads. Consequently, the use of imputed land rent (as input) was not suitable for this study.

Empirical model

Data were analyzed using the stochastic frontier model (Mlote et al., 2013; Cillero et al., 2016). The stochastic production frontier as an econometric method of efficiency measurement in production systems is built around the premise that a production system is bounded by a set of smooth and continuously differentiable concave production transformation functions for which the frontier offers the limit to the range of all production possibilities. It has the advantage of allowing simultaneous estimation of individual technical efficiency of the respondent farmers as well as determinants of technical efficiency. Following Mor and Sharma (2012), the multiplicative stochastic production function is of the form:

$$Q_i = f(X_{ki}, \beta)\, e^{\varepsilon i}, i = 1, \ldots\ldots\ldots\ldots\ldots; k = 1, \ldots\ldots, k \ldots. (6)$$

where Q_i is the output of the i^{th} farm; X_{ki}, is a vector of k inputs used in the i^{th} farm, β is a vector of parameters to be estimated and ε_i is the farm specific composite residual term comprising of a random error term v_i and an inefficiency component u_i.

$$\varepsilon_i = v_i + u_i.\ i = 1, \ldots\ldots\ldots\ldots\ldots\ldots, n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The two components v and u are assumed to be independent of each other, where v is the two-sided, normally distributed error term ($v_i \sim N(0, \sigma_v^2)$, and u is one-sided efficiency component with a half-normal distribution ($u_i \sim N(0, \sigma_u^2$ 1). It follows that the maximum likelihood estimation of Equation (1) yields estimates for β and λ, where β was defined earlier, λ $= {}^{\sigma_u}/_{\sigma_v}$, and $\sigma^2 = \sigma_u^2$. Battese and Corra (1997) defined $\gamma = {}^{\sigma_u^2}/_{\sigma^2}$, so that $0 \leq \gamma \geq 1$ and represents the total variation in output from the frontier attributable to technical efficiency. The farm specific measure of technical inefficiency can be determined from the conditional expectation of u_i given ε_i as:

$$E[u_i/\varepsilon_i] = \frac{\sigma_u \sigma_v}{\sigma}\left[\frac{f^*(\lambda\varepsilon i/\sigma)}{1-F^*(\lambda\varepsilon i/\sigma} - \frac{\varepsilon_i \lambda}{\sigma}\right] \quad i = 1, \ldots\ldots. n \ldots\ldots\ldots. (8)$$

where f^* and F^* are the values of the standard normal density and distribution functions respectively, evaluated at $\varepsilon_i \lambda/\sigma$. The individual farmer's level of technical efficiency (TE_i) is then calculated as:

$$TE_i = \exp(-E[u_i/\varepsilon_i] \quad i = 1, \ldots\ldots\ldots\ldots\ldots n \ldots\ \ldots\ldots\ldots\ldots (9)$$

such that $0 \leq TE_i \leq 1$.

The empirical model of the stochastic production frontier is specified as:

$$I_n Y_{ij} = \propto_0 + \propto_1 I_n X_{1ij} + \propto_2 I_n X_{2ij} + \propto_3 I_n X_{3ij} + \propto_4 X_{41j} + \propto_5 X_{5ij} + \propto_6 X_{6ij} + \propto_7 X_{7ij} + V_{ij} - U_{ij} \ldots\ldots\ldots\ldots (10)$$

The subscripts i and j refer to the i^{th} farmers and j^{th} observation respectively while

Y = total farm output of beef cattle (Kg)
x_1 = Land for beef cattle production (Ha)
x_2 = Herd size of farmers (Kg)
x_3 = Quantity of forage consumed by cattle (Kg)
x_4 = Quantity of feeds/supplements consumed by cattle (Kg)
x_5 = Medicine/drugs administered on cattle (vials)
x_6 = Sum of labour (persons days)
V_{it} = a random error term with normal distribution $N(0, \delta^2)$, U_{it} = a non-negative random variables called technical inefficiency effects associated with the technical inefficiency of production of farmers involved.
I_n = the natural logarithm (i.e. to base e).
$\propto_0$ - $\propto_8$ = parameters to be estimated.

This model was estimated for the three production technologies. Estimation of Equation 10 was accomplished by Maximum Likelihood Estimation (MLE) available in Frontier 4.1 and has been used extensively by various authors in estimating technical efficiency among farmers. Thus following Mlote et al., (2013) in which $v_i \sim N(0, \delta_v^2$) 1, the following log likelihood function could be obtained:

$$I_n X = \sum i\, I_n L_i = \sum i\, [-I_n \delta - \frac{1}{2} I_n \left(\frac{2}{\pi}\right) - \left(\frac{\varepsilon_i}{\delta}\right) + I_n \theta(\frac{-\varepsilon\lambda}{\delta})] \ (11)$$

Where i = number of observations, $\delta = (\delta v^2 + \delta u^2)\, {}^1/_2$

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[1] Beef cattle equivalents were computed by multiplying the number of cattle of various types by conversion factors Otieno et al., (2011); Nwigwe et al., (2015). Following insights from focused group discussions with key informants in the livestock sector in Nigeria, the conversion factors were calculated as the ratio of average slaughter weight of different cattle types to the average slaughter weight of a mature bull. The average slaughter weight of a mature bull, considered to be suitable for beef in Nigeria is 159 kg (FAO, 2013). The estimated conversion factors were 0.2, 0.6, 0.75, 0.8 and 1, for calves, heifers, cows, steers and bulls, respectively.

Table 2. Maximum likelihood estimates of frontier model for nomads, agropastoralists and ranchers.

Variables	Coefficient			T-ratio		
	Nomadic	Agropastoralist	Ranching	Nomadic	Agropastoralist	Ranching
Constant	5.4797***	6.3191***	6.2302***	4.8486	14.1168	12.6011
Farm size	0.6307**	0.8441***	0.9638***	2.3734	2.8042	2.3078
Herd size	0.7993***	0.8391***	0.8885***	2.8993	3.4882	2.9751
Forage	0.4492	0.7104***	0.7915***	0.8831	0.3851	2.6014
Feed/supplement	04986*	0.8033***	0.8535***	1.9145	2.9224	3.1856
Medicine/drugs	0.8883***	0.1112*	0.7971***	2.7990	1.8852	2.8185
Labour	0.1959***	0.4012	0.9971***	2.6538	0.5522	3.2563
AgroEzGu	0.1256	-0.2396***	-0.5598	0.7346	-3.0452	-0.6129
AgroEzFo	0.6741*	0.5942	0.7137***	1.7884	1.1930	-3.1505
Age	-0.3543	-0.8862	-0.3075	-0.5486	-0.8817	-0.1877
Credit	-0.2200	-0.1214***	0.6851***	1.4699	-2.7854	-2.8684
Experience	-0.9358	-0.2870***	1.0736***	1.5689	-2.7854	-2.7429
Coopmembership	0.8680***	0.1140	-0.8294*	-1.7155	0.4996	-1.9284
Semi-formaleduc	-0.2868	0.1116	0.4417	-2.7239	1.3755	-0.7772
Formal-education	0.1125	0.2861	0.8216***	1.1143	3.9345	3.2766
Sigmasquare (σ^2)	0.2893***	0.2967***	0.8264***	6.0863	10.8354	10.3423
Gamma (γ)	0.6376***	0.7278***	0.8115***	3.2463	2.2164	4.3321

Source: Computed from Field Data (2014). AgroEzGu – Guinea savannah agroecological zone; AgroEzFo – Forest agroecological zone; Coopmembership – Cooperative membership; Semi-formaleduc – Semi-formal education; ***Significant at P ≤ 0.01; **Significant at P ≤ 0.05; *Significant at P ≤ 0.10.

λ = $\delta u/\delta v$, $\varepsilon_i = v_i - u_i$ and θ is the normal distribution.

In addition to determining farmers' technical efficiency in beef cattle production, the study also went further to identify the determinants of farmers' technical efficiency in terms of socioeconomic variables and as such an inefficiency model was specified to examine the effect of these variables (z) on the technical efficiency (u_i) of the farmers in beef cattle production. The model which assumes that the inefficiency effects are independently distributed having $N(0, \sigma_u^2)$ distribution and mean u_{it} is of the form:

$$u_i = \delta_0 + \delta_1 z_1 + \delta_2 z_2 + \delta_3 z_3 + \delta_4 z_4 \quad \text{………………………..…….(12)}$$

where:
z_1 = Guinea Savanna agroecological zone (1 = Yes, 0 = No)
z_2 = Forest agroecological zone (1 = Yes, 0 = No)
z_3 = Age of farmers (years)
z_4 = Access to credit by farmers (1 = Yes, 0 = No)
z_5 = Farming experience of the farmers (years)
z_6 = Coopmembership = Membership of Cooperative society (1 = Yes, 0 = No)
z_7 = Semi-formal education = Attainment of semi-formal education (1 = Yes, 0 = No)
z_8 = Formal education = Attainment of formal education (1 = Yes, 0 = No)

RESULTS AND DISCUSSION

Input and socioeconomic variables of beef cattle farmers by technology

Average input use among the sampled farmers is presented in Table 1. Most of the beef cattle farmers are of the small and medium scale categories. Ranchers had relatively larger farms; it was observed that the average farm size of ranchers was 4.86 ha. The commercial ranching system is capital intensive and required specialized production skills and markets that demanded quality product, to ensure returns on investment. The average farm size among the agropastoralist was found to be 3.26 ha while that of nomads was found to be 1.64 ha. The mean herd size of the nomads was found to be 49 (TLU). It was also discovered that about 90.2% of nomads generally keep large herds of cattle of indigenous breeds such as Zebu and Boran, which were relatively well adapted to dry and hot areas, and are resistant to common local diseases but grow slowly and respond poorly to fattening. The average herd size of the agropastoralists was found to be 42 (TLU); the herd size which was found to be majorly made up of indigenous breeds is also like that of the nomads.

The proportion of mature males (bulls) in the agropastoralists' herd composition was found to be extremely low, suggesting higher off take rates of males at relatively young age. The herd size of the agropastoralists was on the average smaller than those of the nomadic system, possibly because they did not solely rely on cattle production. The average herd size of the ranchers was found to be 53 (TLU). The animals were usually weaned, castrated and sprayed against tick-borne diseases. Compared with agropastoralists and

Table 3. Frequency distribution of technical efficiency among the major beef cattle farmers.

Range of technical efficiency	Frequency			Absolute percentage		
	Nomadic	Agropastoral	Ranching	Nomadic	Agropastoralist	Ranching
< 50	13	32	0	14.14	15.38	0
50 < 60	12	9	3	13.04	4.33	7.69
60 < 70	23	86	3	25.00	41.34	7.69
70 < 80	20	42	8	21.74	20.19	20.52
80 < 90	16	36	18	17.39	17.32	46.16
90 < 100	8	3	7	8.69	1.44	17.94

Computed from Field Data (2014). Mean Technical Efficiency 59.00% (Nomadic); Mean Technical Efficiency 69.00% (Agropastoralists); Mean Technical Efficiency 83.00% (Ranching).

ranchers, nomads used less improved feeds (21 kg). This could be attributed to their nomadic nature, which made natural pasture more available to them. However, the ranchers used relatively less natural pasture (forage), per unit of output, which is an indication that they keep better cattle breeds. Agropastoralists incurred more veterinary costs (medicine/drugs), followed by the nomads. This could be due to the fact that agropastoralists' farms are usually located in the interior, which made them to have relatively less access to subsidized veterinary services than the nomads and ranchers.

The nomads made use of 204 persons' days of family labour, agropastoralists used 198 persons' days of family labour while ranchers used 102 persons' days. On the contrary, the ranchers used more of hired labour, followed by the nomads while the agropastoralists were the least in the use of hired labour. The amount of person's days of labour recorded in each case for the three technology groups is a clear indication that Nigerian beef cattle production is still highly labour intensive. Ranchers however incurred more labour costs than the other production systems. This could be attributed to larger farm size and intensive production system employed by the ranchers. The average age of the nomads was estimated to be 47 years while that of the agropastoralists and ranchers was 47 and 44 years respectively. In the three production systems, it was discovered that the farmers were young and active; however, the average age is tending towards the declining productivity class of greater than 50 years. The implication of this is that except the occupation witnesses the injection of young able men, in the next one decade, many of these farmers would have reached the declining productivity level and beef cattle production in the country will suffer a setback.

The percentage of ranchers who had formal education was found to be 48.7% while that of nomads and agropastoralists was found to be 15.9 and 23.0% respectively. Nomads were found to be more experienced than the agropastoralists and ranchers with average of 20 and 17 years of farming experience respectively. Majority of the farmers in all the production systems were males; the mean household size across the production systems was found to be 11 persons. A higher percentage (59.0%) of ranchers used controlled cattle breeding, which involves use of artificial insemination (AI) or planned and monitored natural breeding rather than random natural breeding. This was consistent with the observation that the more commercially-oriented farmers (ie, ranchers and agro-pastoralists) preferred cattle breeding strategies that target market and/or profitability requirement, e.g. faster growth and higher gains in live weight, while the relatively less-commercialized nomads mainly focused on cattle survival traits such as drought resistance, hardiness and disease tolerance (Otieno et al*.,* 2012). It was finally discovered that about 71.8% of the ranchers had access to credit facilities while the agropastoralists had the least, followed closely by the nomads.

Technology and technical efficiency of farmers

Table 2 presents the result of the maximum likelihood estimates for the three groups of farmers while the distribution of technical efficiency among the farmers was presented in Table 3. The diagnostic statistics of the model showed log likelihood function of 73.221769, 107.89968 and 132.105385 for the nomadic, agropastoralist and ranching systems, which were significant at 1% level, indicating that the model had a good fit to the data. The mean efficiencies were found to be 0.59, 0.69 and 0.83 for the nomadic, agropastoralist and ranching production systems. From Table 3, herd size, feed/supplements, medicine/drug and labour contributed significantly to the technical efficiency of the farmers. The coefficient of the number of cattle (herd size) was positively significant at 1% level of significance across the three production systems, implying that herd size yielded a revenue increase of 0.79, 0.83 and 0.83 Naira in the nomadic, agropastoralist and ranching systems. In other words, the allocation and utilization of the herd size was in stage II of the production surface and thus it was efficiently allocated and utilized.

The coefficient of the feed/supplement for the nomadic system was 0.49 and positively significant at 10% level of significance, implying that feed/supplement yielded a revenue increase of 0.49 Naira. However, the coefficients of feed/supplement were 0.80 and 0.85 in the agropastoralist and ranching production systems and were significant at 1% level of significance, implying that feed/supplement yielded a revenue increase of 0.80 and 0.85 Naira in the agropastoralists and ranching systems. This result could be attributed to the fact that the nomadic system (nomadic pastoralists) which is a traditional cattle production system relies majorly on natural pasture (forage) for animal rearing; this is unlike the ranching system which is highly commercialized and also the agropastoralist system which usually face challenge from land pressure and limited pasture (forage) for their cattle due to the sedentary nature of the system.

The coefficient of medicine/drug were 0.88 and 0.79 for the nomadic and ranching systems respectively and was positively significant at 1% level of significance, implying that medicine/drugs yielded a revenue increase of 0.88 and 0.79 Naira for the two production systems respectively. In the case of the agropastoralist system, the coefficient of medicine/drug was 0.11 and positively significant at 10% level of significance, implying that it yielded a revenue increase of 0.11 Naira. The agropastoralists were found to expend more in purchasing medicine/drugs and other professional veterinary services as compared to ranchers and agropastoralists. This could be due to the fact that agropastoralist farms are usually located in the interior, which made them to have relatively less access to subsidized veterinary services than the nomads and ranchers.

The coefficient of labour were 0.19 and 0.99 for the nomadic and ranching systems respectively at 1% level of significance, implying that labour yielded a revenue increase of 0.19 and 0.99 Naira for the two production systems. However, it was discovered that labour was not significant in the agropastoralist system. The result could be attributed to the fact that agropastoralists usually own land rights which makes it possible for their farms to be located relatively close to their homesteads and therefore labour is more available to them than the nomadic and ranching production systems. It was also observed that forage which is a critical input in cattle rearing was not significant in the nomadic system. The result could be due to the fact that natural pasture (forage) is in abundance in the case of the nomadic pastoralists who migrate from place to place in search of pasture. However, forage was found to be significant in both the agropastoralist and ranching production systems.

There is presence of technical inefficiency effects in the beef cattle production systems in Nigeria; this is confirmed by the large and significant value of the gamma coefficient (γ). The signs and significance of the inefficiency model of the stochastic frontier production function had important implications on the technical efficiency of the production systems. In the nomadic production system, the coefficient of age, credit, farming experience and semi-formal education were found to be negative but less than unity. This indicated that these factors led to increase in technical efficiency. The coefficient of the agroecological zones and attainment of formal education were found to be positive and less than unity, which implies that these factors led to decrease in technical efficiency. These results can be attributed to their nomadic nature.

In the agropastoralist system, the coefficient of credit, farming experience and guinea savannah agroecological zones were found to be negative and more than unity. This indicated that these factors significantly led to increase in technical efficiency; the coefficient of age was also found to increase the technical efficiency. The coefficient of forest agroecological zone, cooperative membership and educational attainment were found to be positive and less than unity, which implies that these factors decrease the technical efficiency of the agropastoralist system. In the ranching system, the coefficient of guinea savannah agroecological zone, age, cooperative membership and educational attainment were found to be negative and more than unity. This indicates that these factors significantly led to increase in technical efficiency. However, forest agroecological zone and access to credit facility led to a decrease in technical efficiency in the ranching production system.

The mean technical efficiency of 0.59, 0.69 and 0.83 for the nomadic, agropastoralist and ranching systems showed that, given the level of technology of this group of farmers, there is still much to be done to increase their production capacity.

Limitations of the study

The collection of the needed data and its computation and subsequent analysis was a difficult part of the study. The unwillingness of some local sources (respondents) to provide necessary data, which led to the rejection of some questionnaire were also major limitations. Considering annual value of beef cattle output alone was also a limitation but due to measurement difficulties, physical weight of cattle could not be taken. Also due to measurement problem, the local herbs used, especially by the nomads in the treatment of their cattle were not considered.

Conclusion

The study examined the Technical Efficiency (TE) of the three major beef cattle production systems in Nigeria given the technologies. One major finding emanating from this study is the fact that increases in beef output in

Nigeria can be achieved by improving the performance of the production systems using the existing technologies since most of the critical inputs significantly influenced technical efficiency; also labour and herd size were identified as major inputs in beef production in Nigeria. Policy attention should therefore be directed towards providing labour saving technology to ease farm operation; emphasis should also be placed on hybrid development so as to increase the herd size of cattle. The study also showed that the technical efficiency of the three production technologies were significantly different at 5% level of significance; ranching system was found to have the highest mean efficiency of 83%, followed by the agropastoralists and then the nomadic system. There is need for further investigation into the factors that led to the difference in the technical efficiency of the systems; this kind of study will require different methodology and analytical approach. It will, however, provide better insight and useful explanations as regards the issue of technology adopted by the systems and why some farmers prefer to stick to the nomadic production systems in spite of its lower efficiency. Such study will also expose the difference in technology and perhaps environmental factors that could affect beef cattle production in Nigeria.

Conflict of interest

The authors have not declared any conflict of interest.

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