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Review

Treatments and utilization of swine waste in Brazil

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Swine wastes obtained from farming activities have the greatest impact on the environment by environmental agencies. Swine wastes together with poor management represent risks to the environment. In Brazil, these activities significantly increased in the last years and from 2014, the country became the fourth largest producer in the world. Swine wastes are generated in high amounts due to the confinement system used nowadays. This, coupled with the poor management of these wastes is now a serious problem to the environment. Therefore, the treatment of this waste is essential to maximize integration between environment and production. Based on this, the aim of this study is to perform a bibliographic survey of the swine waste treatment used mostly in Brazil and the ones that stand out most.

Key words: Swine waste, reuse, environment.

INTRODUCTION

Unlike other agribusiness production chain, Brazilian pig farms have grown significantly over the years. This growth is perceived when social and economic indicators are analyzed. Pig production of the past evolved technologically and activated the models of the rural and agroindustrial producers.

Among the agricultural activities, the production of pigs is considered to have the greatest environmental impact, because it has a high polluting power. A farm with 600 animals has a polluting power just like a number of 2100 people (Diesel et al., 2002; Rizzoni et al., 2012). Targeted as a practice around the world, swine breeding is important for the social and economy development of countries. The largest world producer in the year 2015 was China with a production of 56375 (thousand/t), followed by Europe with an approximate production of 56375 (thousand/t) and United States with a production of 11158 (thousand/t). Brazil ranked fourth with a production of 3643 (thousand/t), followed by Russian with a production of 2630 (thousand/t) (USDA, 2016).

The swine industry got a major breakthrough in Brazil when it began to introduce new technologies primarily in

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Table 1. Physical and chemical features of the swine waste.

Parameter	Medium values
pH	7.8
Alkalinity (mg/L)	3135
Ammoniacal nitrogen (mg/L)	4.26
Total solids (%)	18.9
Volatile solids (%)	76.4
COD (g/L)	210.0
K (mg/L)	293
Ca (mg/L)	64
Mg (mg/L)	13
Fe (mg/L)	1.6
Cu (mg/L)	0.8
Zn (mg/L)	0.5

Source: Huang et al. (2015, 2016).

the areas of genetics, nutrition and health (Espindola, 2012). The total production of pork meat in Brazil that was exported had an approximate value of 1279 (thousand/t), which triggered revenue of 555 million dollars. The south states are predominately responsible for the country's exports accounting for 80.3% of the total. The main countries importing Brazilian pork are located in Extra-EU Europe, Oceania, the Middle East and the European Union (ABPA, 2016).

The Brazilian production of pork meat occurs in small and medium scales using the model of confinement, along with escalating consumption of pork meat. There had been an increase in its production, and such activity is directly dependent on natural resources, requiring a high water demand and generating a high wastes amount which should be properly treated. This is why it is necessary that here must be proper awareness of the impact of such activity upon water resources and the environment (Gomes et al., 2014; Schneider and Carra, 2016).

The effluent coming from this activity has a high content of suspended solids and organic matter, and high concentration of nutrients, mainly phosphorus and nitrogen (Chelme-Ayala et al., 2011).

Studies on the levels of contamination of water resources have been increasing due to the launching of swine manure without proper treatment (Schoenhals et al., 2007). The present study aims to study the main forms of treatment and subsequent use of swine waste in Brazil.

BIBLIOGRAPHIC REVIEW

Residuary waste water from swine farming

Swine farming activity directly influences the socio-economic and cultural aspects of a nation that uses it for subsistence farming. However, it is considered a low environmental quality activity; it is hazardous to water, soil and air, causes unpleasant odors, insect proliferation on site and environmental discomfort to people living near it (Belli Filho et al., 2001). A study by Carvalho et al. (2015) demonstrates that about 62% of the farms studied had their environmental management system considered unsatisfactory and potentially generating environmental risks.

Due to the fact that the pig production system in Brazil is confinement type, it results in higher water consumption on the premises and therefore increases in the production of water waste. The amount of residuary wastewater which is generated may vary between 5 and 10 L $swine^{-1}.day^{-1}$ (Schoenhals et al., 2007; Batista et al., 2013).

This amount of swine manure will vary according to the animal development; on average, the values are 4.9 to 8.5% in relation with the live weight per day in the range of 15 to 100 kg. That is, on average, adult pig produces between 7 and 8 L of liquid waste per day or 0.21 to 0.24 m^3 per month (Diesel et al., 2002). Orrico Junior et al. (2010) evidenced that the composition features of swine waste are related to the quality and quantity of the reasons for which it is used. With this in mind, it triggers a larger variation in concentration of each component as present in the waste. In Table 1, it can be observed the physical and chemical features of untreated swine waste.

The large production of waste in a small confinement causes an environmental concern. With the study of new technologies for proper treatment and the proper release of such waste, the Brazilian farmer finds it difficult to reach these technologies which are interfered by factors such as the capacity of the soil and the plant to receive such water waste, the finance available for investment in equipment used for proper treatment of such effluents (Kunz et al., 2009).

Treatment systems applied on swine waste

The improper handling of swine waste causes damage to the environment, such as the emission of harmful gases and pollution of water sources from the surface water as well as to the groundwater (Cardoso et al., 2015).

The emergence of new alternatives for the treatment of swine waste is evidenced to be more efficient compared to the environmental impact which it generates by treatment upon the possibility of reutilization of waste and recycling of nutrients (Kunz et al., 2016).

Phase in, phase out separation

There are techniques used to separate waste into solid and liquid phase in and out, enabling waste management.

In the physical processes, effective decomposition of waste only reduces the complexity of these fractions making it suitable for treatment or storage (Higarashi et al., 2007).

According to Kunz et al. (2016), it is essential to use phase in and out separation for the treatment of swine waste, and high concentrations of suspended sedimentary deposit as well as solids.

Waste separating sieves

Sieving process is very important to avoid overloading with solid and subsequent treatment processes, separating the liquid portion of particles in larger grain sizes (Ramme and Kunz, 2009). The sieves are classified into static, vibratory and rotary, with different types of settings and capabilities. The solid sieving removal capacity is between 3 to 10% for the static and 40% for the vibratory, bearing in mind the lower removal rate from the one obtained by decantation (Oliveira, 1993).

Less diluted waste and lower storage time may reduce BOD, COD, total solids, fixed, volatile and total phosphorus of up to 80% and total nitrogen of about 60% (Higarashi, 2005). Orrico Junior et al. (2009) demonstrated that the use of sieves for the separation of solid fraction of swine wastewater potentiated the efficiency of biodigesters, produced higher amounts of biogas with a higher methane content in the gas and the biofertilizer presented higher levels of mineral elements.

Decantation

Sedimentation is a process in which the flakes in suspension are removed from water by using gravitational forces in order to separate particles of higher density from water, placing them on the surface (Netto and Richter, 2001).

It is considered an effective split system, of a low cost and easy to operate. However, its disadvantage is the high sludge production. This process can be applied for the swine wastes treatment since it promotes high efficient treatment and biofertilizer quality. Decantation removes approximately 50% of solid materials from wastes, with a volume of 15% of the total liquid waste produced (Dartora et al., 1998).

Chemical processes

Flocculation agents: The efficiency and speed of separation stages can be enhanced for the removal of solids with the use of flocculating agents, chemical compounds that act as aggregate particles in suspension. They mold bigger dimensioned flakes and then facilitate the decantation separation processes or by sieves. The flocculating agents most used are inorganic salts of aluminum or calcium and iron. Therefore, the disadvantage of these compounds is the high concentration required, which requires a high amount of flocculants (> 1500 mg/L), resulting in a large volume of sludge with high concentrations of metals. An alternative to these are organic polymers such as polyacrylamide (PAM) and natural organic flocculants such as tannin. The addiction of flocculating agents allows better formation of the flakes and better sedimentation of the sludge (Higarashi et al., 2007; Orrico Junior et al., 2009).

Biological processes

After the separation phase, the solids and liquid fractions are addressed to different treatments depending on the physicochemical feature of the waste in order to increase the treatment efficiency. The liquid fraction passes through aerobic and anaerobic biological treatment processes for the production of biogas and/or liquid fertilizer and the solid fraction is treated by composting of biogas (Higarashi et al., 2007).

Anaerobic treatment: Anaerobic digestion is a recycling method which renders the gas fuel and bio-fertilizer production, from the organic waste material of both animals and plants. When it is intended to preserve natural resources and recycling of organic materials reuse of swine manure is of great benefit for environmental sustainability (Andrade et al., 2012). Treatment of waste through anaerobic digestion emerges as an important alternative without high cost and it is efficient in reducing organic matter (Amaral et al., 2014).

Basically, the process of anaerobic digestion occurs in two phases. In the first, occurs the transformation of complex organic matter by extracellular enzymes; acidogenic and acetogenic bacteria are responsible for the degradation into simple compounds like volatile organic acids (CO_2 and H_2). In the second phase, these simple compounds are transformed by archaea methanogenics into CH_4 and CO_2. This part of the process occurs more slowly and the microorganisms are more sensitive to environmental conditions (Souza, 1984).

In addition to be strictly anaerobes, it requires a pH under neutral parameters and a temperature higher than 15°C. In case of unfavorable conditions and if its development is interrupted, there is stagnation of DBO removal and accumulation of acids triggering bad odors. The anaerobic matter decomposition process through anaerobic microorganism till date is the most widely used because of the swine waste present in ideal conditions for the development and permanence of such microorganisms (Von Sperling, 1996).

The anaerobic process is realized with the metabolization

Table 2. Averages (g/L) of the organic load determinations and nutrients for feeding purposes and the effluent from the digester from March 2004 to April 2005.

Parameter	Affluent	Effluent	Reduction (%)
COD	65.09 ± 14.56	8.27 ± 1.58	87.3
BOD_5	34.30 ± 8.11	3.00 ± 1.34	91.25
$N\text{-}NH_3$	2.52 ± 0.75	2.36 ± 0.63	6.34
N-NTK	4.53 ± 1.07	3.14 ± 0.50	30.68
P_{TOTAL}	1.60 ± 17.54	0.22 ± 0.02	86.25
Volatile solids	39.22 ± 17.54	8.29 ± 4.57	78.86

Source: Kunz et al. (2005).

of organic matter in an oxygen free environment. Degradation of this organic matter is realized into four different metabolic processes and via various groups of microorganisms (Khanal, 2008).

Manure compost dumps-dunghill: It is a place where the volume of manure produced in the creation system is disposed. It rests for a time (between 4 and 6 months), where it undergoes an anaerobic fermentation and then is tapped as fertilizer. In this process, any separation phase occurs, therefore, even with the DQO removal, the manure remains concentrated, requiring larger areas for its final disposal (Diesel et al., 2002).

Anaerobic pond: They are customized biological reactors to receive high organic loading per reactor unit volume. There is the absence of oxygen, photosynthetic activity, and digestion in association with fermentation and anaerobic respiration (Oleszkiewicz, 1986).

It is a process rendered as a primary treatment of swine waste with high concentrations of organic compounds and high solids content, which is the purpose of the partial stabilization of organic raw material (EMBRAPA, 1995).

Facultative pond: Facultative pond is a type of biological treatment of organic matter stabilization and is featured by having two layers: aerobic layer (top) and anaerobic layer (lower). Generally, it is applied as second treatment after the anaerobic treatment. It reduces the number of pathogen organisms and increases the treatment efficiency (Von Sperling, 1996).

After the effluent enters the pond, the fragmented DBO settles down, forming a bottom sludge (deposit of sedimented organic material) which undergoes a treatment in the anaerobic zone of the pond; while the dissolved organic matter (soluble COD) and suspension (low particulate BOD) have aerobic treatment on the surface of the pond. Oxygen responsible for such degradation is in charge of the liquid surface gas exchange with the atmosphere by photosynthesis done by some algae (Earnest, 1971).

Still according to the author quoted above, major profundity of the lagoons positively assists in the environmental anaerobic facultative maintenance; it reduces lose by evaporation and provides lower salinity to the effluent, which is a positive characteristic for its use in the fertigation activity.

Bio-digester

For more than two centuries, knowledge about biodigester already exists, where it responds well to the use and treatment of waste, power generation and biofertilizer production (Ferreira and Silva, 2009). With the necessity to find an adequate treatment to the wastes coming from animals, the treatments realized with biodigesters are attractive, because in addition to reducing their pollution factor, they generate biogas and biofertilizer that can be used later to generate profit for producers (Frigo et al., 2015).

Bio-digester is an alternative to the use of swine waste; it decreases soil and water contamination, and still produces biogas as a source of energy and bio-fertilizer for crops and pastures. With the proper treatment in bio-digester, the manure can be used in farming areas according to their needs. This reduces the use of chemical fertilizers, improves soil structure and increases crop production capacity (Da Silva et al., 2012).

The advantages of using biodigesters are: the low operational and deployment costs; simplicity of operation, maintenance and control, are efficient in removing various categories of pollutants, have low requirements, can be applied on a small scale with little dependence on the existence of large interceptors, have high useful life and the possibility of recovery of useful by-products such as biofertilizer and biogas (Samulak et al., 2010). Regarding the operation mode, bio-digester may be continuous or discontinuous and the treatment efficiency may vary according to the concentration residue and the residence time thereof in the digester (Campos, 1999). In Table 2, the average removal was observed after the treatment of swine waste with anaerobic bio-digestion. Vivan et al. (2010) evidenced in her studies that digester compound and stabilization ponds are effective for the treatment of swine waste, and reduction of organic matter.

Hydraulic retention time (HDT)

Hydraulic retention time is defined as time required for the residue to be digested through the digester. It is determined in a continuous process by the relationship between the digester volume and daily volume of introduced charge. The HDT is directly related to the speed of the degradation process, with the dilution and the total solids content of the substrate. It targets the end of the process in relation to the treatment and reduction in COD (Magalhães, 1986).

In the continuous flow structures, each organic charge which arrives generally needs an HDT of 30 to 50 days depending on the room temperature in which the digester is deployed. This time can be reduced by stirring and temperature increase (Florentino, 2003). Silva (1996) studied the hydraulic retention time of waste in anaerobic pond, with volumetric organic loads of 0.03; 0.05; 0.07 kg of BOD_5/m^3/day; in 30 days, the best performance was the one with initial load of 0.05 BOD_5/m^3/day. Costa et al. (1995) studied degradation of swine waste with organic volumetric load of 0.03 to 0.12 BOD_5/m^3/day, in anaerobic ponds, and HDT for 66 days. There was a reduction on the average of 85% of COD, in 117 days (90%).

Biogas production

The production of biogas through anaerobic digestion process is common in rural areas because of its low operating costs and clean fuel capacity (Cheng et al., 2015). The biogas produced in anaerobic conditions is composed of methane (60 to 70%), CO_2 (30 to 40%), H_2S, NH_3, hydrocarbons and some other compounds. The consumption of 1 g of DQO eliminates the medium to 0.36 L of methane. The performance in the production of biogas by means of microorganisms is a function of several variables, such as C/N, environmental conditions (pressure and temperature) and operation (temperature, pH and HDT, volume availability, organic load) (Hohfeld and Sasse, 1986).

Swine waste under anaerobic process and favorable temperature and pH conditions produce methane in variable proportions. The fermentation product has a deodorization of 80 to 90% pollutant load reduction of 60 to 70%, and the concentration of fertilizer elements is similar to the undigested swine manure waste (Gosmann, 1997).

Biogas produced by swine manure waste is a renewable source of energy because it can be converted into electrical energy that can be used to meet the needs of farmers and properties and also contributes to the reduction of environmental damage (Avaci et al., 205). In studies conducted by Campos et al. (2005) on the evaluation of biogas production potential and the anaerobic treatment efficiency sludge cover (UASB) as fed by swine waste, the average production of biogas and methane ranges from 0.03 and 0.36 L/day, with an average performance of 0.14 L/day. According to Trevisan (2013), for biogas produced by swine manure supplemented with ractopamine, there was a biogas production between 0.024 and 0.029 m^3/kg, with TDH of 35 days.

Avaci et al. (2013) evidenced that when a farmer generated income from carbon credit sales in just one single situation, he had a loss of approximately 82 thousand real when 10 $hday^{-1}$ was generated and there is the amortization loop of 10 years. The farmer insisted on the generation of electricity. This is because till date carbon credit industry is more favorable to farmers; in addition to being an area that is booming in the world, it contributes to the environment, and is a source of income for both large and small farmers.

Hydrogen production

Studies regarding hydrogen production are limited to the use of synthetic substrates rich in carbohydrates (glucose, sucrose and starch), which are easily degradable consortium of H_2, therefore, producing microorganisms. However, such practice is not economically viable. In this context, some agricultural/industrial by-products rich in organic matter, supplemented with synthetic substrates, may pass to enable the production process for cost reduction (Ismail et al., 2010) (Liu et al., 2011).

To Wagner et al. (2009) and Wu et al. (2013), swine waste has high concentrations of nitrogen and phosphorus, and when used as the only substrate in fermentation, some bio-hydrogen is produced; however, they are likely to be used as glucose in other substrates in anaerobic reactors conducted in batch.

Wu et al. (2009) and Zhu et al. (2009) obtained satisfactory results with the addition of glucose residue, reinforcing the hypothesis that it is a good co-substrate for fermentation with carbon rich materials.

Tenca et al. (2011) evaluated the application of swine manure as co-substrate in the production of hydrogen by thermophile fermentation residues of fruits and vegetables, in order to maximize production, where the swine manure waste would serve as a buffering agent. The percentage for greater gas production rate was 65% of swine waste and 35% of fruit and vegetable waste, thus avoiding the need of adding alkali substance in the reaction vessel.

H_2 production fermentation using acid crops is a highly complex process influenced by several factors such as reactor configuration, hydraulic retention time, the substrate specificity as the organic load, pH, temperature, redox potential and nutrients. According to Wu et al. (2010), among such parameters, pH is one of the most significant, because it directly affects the hydrogen and metabolic pathways, as it inhibits methanogen activity, maximizing the production of bio-hydrogen.

According to Alves et al. (2013), biogas has a great potential in the production of hydrogen. However, this production depends on several factors such as the composition of biogas, the purity required for the production of H_2 and the availability of investment in this technology.

Bio-fertilizers

The effluent generated on the biodigester is called biofertilizer, but this effluent cannot be directly discarded in water resources, since even though it has undergone a treatment process, it still presents high polluting potential. This fertilizer can be used in agriculture, but for its proper use it is necessary to follow the same indications of the chemical fertilizers (Kunz et al., 2005).

Bio-fertilizers present a high quality because they have certain characteristics such as the reduction of carbon material. The digested organic matter releases carbon in methane and carbon dioxide. It increases the nitrogen content and other nutrients, as a result of carbon release. It decreases in the carbon/nitrogen ratio (C/N) of the organic matter, which improves agricultural use. The use of bio-fertilizer by microorganisms in the soil is easier, since the degree of decomposition is advanced. Already there is a part of the solubilization of nutrients, making it more available to plants. Besides bio-fertilizers can be used to control pests and diseases inured to agricultural crops (Oliver and Neto, 2008).

Panzenhagem et al. (2008) used bio-fertilizers in the installation of fruit farming; they enhanced the best performance of citrus trees and enabled the planting of annual intermediate species, such as maize, cassava and beans, particularly in the early years of citrus plants development. Oliveira et al. (2011) demonstrated that the use of biofertilizer in coffee and corn plantation represents only 40% of the total fertilizer needed for plant nutrition and development. Because of this, it is necessary to perform mixed fertilization with chemical fertilizers to keep production up.

According to Sediyama et al. (2014), the increase in the applied doses of biofertilizer improves nutrition and the productivity of colored pepper, when the culture system is organic. The author also showed that biofertilizer from swine manure has potential for fertilization in the unconventional form of soil, brings positive reflexes in the foliar contents of nutrients and the commercial productivities and early appearance of extra fruits. Seidel et al. (2010) demonstrated that the use of biofertilizer in corn crop provided the same results with chemical fertilizer, demonstrating that this is a viable option for farmers.

Water reuse in agriculture

According to Asano and Levini (1996), the reuse of wastewater in agriculture through sewage in the soil or irrigation took place in Athens from time immemorial, before Christianity came. The United States' planning and reuse of wastewater occurred in the early twentieth century (Asano and Levini 1996). The use of wastewater started in sugarcane mills, by using effluents from mills/distilleries, in order to irrigate sugarcane plantations (Leite, 2003). In agriculture, the use of such alternative water is important, enabling the use of nutrients for the growth of various plants (Pereira, 2006).

The swine residuary wastewater (SW) has enough nutrients to be taken in the ferti-irrigation of diverse cultures. It increases production and productivity. In wastewater, there is almost 100% potassium, a third quarter of phosphorus and almost two thirds of nitrogen; in mineral form the nutrients that are not available in organic form can be utilized by the plant (Gomes et al, 2001). According to Freitas et al. (2004), the maize culture silage, when irrigated with wastewater, increases the productivity of green matter, with an average values from 45 to 46 t ha^{-1}, about 50% higher than irrigated water supply. There was also an increase in plant height values, corn cob statistics, length and weight of corn cobs.

Hermes et al. (2012), evaluating the development of the soybean crop with swine wastewater, observed the application of such water induced a greater absorption of nitrogen and lower absorption of potassium, an increase on the height of the plant, green mass and leaf area as well as an increase in soybean productivity. Constant ARS application as fertilizers favors a greater accumulation of nutrients such as phosphorus, potassium, copper and zinc in the surface of soil layers as compared to mineral fertilizer (Scherer et al., 2010). Dieter (2009) said that there are losses of nitrogen and phosphorus flow and observed highest peaks of eutrophication in source of water. Medeiros et al. (2015) observed that the cotton cultivars that were fertilized with swine wastewater obtained a better performance of dry mass, absorption and accumulation of nutrients when compared to the crop that was not irrigated with this biofertilizer. Souza et al. (2013) observed that the production of sweet peppers was not contaminated by coliforms termotoleranets and *Salmonella* ssp., when using wastewater from swine after preliminary treatment.

Bosco et al. (2016) concluded that nitrogen functional groups are released into the soil when swine manure undergoes some treatment process, thus demonstrating the great potential of reusing swine wastewater in agriculture as a form of fertigation.

CONCLUSION

Swine farming is a crucial activity in Brazilian economic sector. As such, it needs to be developed as it reduces costs and increases productivity. Swine waste is produced in large amounts due to specialization and agglomeration of a vast number of farm herds, and the improper handling of such manure is the major problem that affects environment. Therefore, the treatment of such waste is essential for the proper integration between environment and production.

It is a process which offers several benefits, from environmental to economic and social. In addition to causing degradation of organic matter present in the waste, there is a generation of bio-fertilizers, which can be rendered in agricultural and biogas premises, having the advantage of the co-generation of thermic or electric energy.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of edible coating materials and stages of maturity at harvest on storage life and quality of tomato (*Lycopersicon Esculentum* Mill.) fruits

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Tomato (*Lycopersicon esculentum* Mill.) fruits due to their high moisture content are spoiled and deteriorate in short period of time. Once fruits are harvested, respiration and transpiration are the two major physiological processes that significantly affect storage life and quality of the fruits. However, effects of these processes can be minimized through optimizing harvesting stage of fruits and applying physical barriers for oxygen diffusion and moisture migration. The aim of this work was to investigate the combined effect of stage of harvesting of fruits and application of edible coating materials on storage life and quality of tomato fruits. Treatment combinations were the three harvesting stages of the fruits (mature green, turning and light red stages) and two coating materials (pectin and chitosan with control). Treatments were laid out in a completely randomized design with three replications. Sample fruits were evaluated periodically for different parameters. The study showed that, coating of tomato fruits delayed the ripening process with better fruits quality than uncoated ones. Combined treatment combinations resulted in a significant delay in the change of weight loss, disease incidence, disease severity and ripening index as compared to control fruits. Moreover, in terms chemical parameters, coated fruits revealed higher amount of ascorbic acid, lycopene and phenolic contents. Fruits coated with either chitosan or pectin at turning stage of maturity showed relatively better results for most of the quality parameters. Maximum shelf life was observed for fruits harvested at turning stage coated by pectin (17 days) and chitosan (16 days) films than control (10 days) at the same stage of maturity. Therefore, storage life of the fruits with better quality can be extended by combining optimum stage of harvesting with use of edible coating materials.

Key words: Tomato, harvesting stage, edible coating, pectin, chitosan, storage life.

INTRODUCTION

Tomato is one of the vegetable crops which is widely consumed either raw or after processing and can provide a significant proportion of the total antioxidants in a diet (Martinez-Valverde et al., 2002). Its antioxidants are like vitamin C and E, lycopene, ß-carotene, flavonoids and other phenolic compounds (Dumas et al., 2003). Their

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activity is based on inhibiting or delaying the oxidation of biomolecules in human body by preventing the initiation or propagation of oxidizing chain reactions (Radzevicius et al., 2009). In addition to this, the fruit also consists of different sugars, acids, phenols and minerals and significant amount of water. However, due to its high moisture content, the fruit is subjected to high rate of metabolic degradation in ambient air. Due to these reasons fast ripening after harvest and softening as well as deterioration during storage is a major problem (Kader, 2008). In tropical countries, about 40 to 50% of post-harvest losses occur between harvesting, transportation and consumption of fresh tomato due to short storage time (Kader, 1992). A study conducted in central rift valley of the country, a postharvest lose of 20.45, 8.63, 2.93 and 7.3% were observed at producers, wholesalers, retailers, hotel and cafeteria levels with a cumulative loss of 39% (Gezai, 2013). Similarly, a study conducted around Dire Dewa region, showed that estimated postharvest losses of tomato was 45.32 (Kasso and Bekel, 2016). This large annual loss of tomato fruits has a great economic and nutritional implication unless and otherwise appropriate ripening control measures are taken to prolong storage life with better quality retention (Hoberichts et al., 2002).

Proper harvesting stage determines the nutrient contents as well as storage durability of any fruit. It was found that maturity stage is an important factor that influences the consumer preferences (Casierra-Posada and Aguilar-Avendaño, 2009). Depending on distance of market, purpose of use and production area, tomatoes can be harvested at different stages of maturity from mature-green stage to full ripe stage. Once harvested, it is recommended to minimize the respiration and transpiration rates of fruits using different methods. Low temperature storage is a recommended method but not feasible for small scale farmers in developing counties. However, in recent years, there is increasing interest to use edible coatings to maintain fruit quality (Tzoumaki et al., 2009). Edible coatings can provide an alternative option to extend postharvest life of fresh fruits with or without low temperature storage. It also has the same effect as modified atmosphere storage or packaging where the internal gas composition is modified (Park, 1999). Edible coating acts as a semi-permeable barrier against O_2, CO_2, moisture and solute movement, thus reducing respiration rate, water loss and oxidation reaction and then helps to maintain internal quality and appearance (Arvanitoyannis and Gorris, 1999). The use of edible coating has also received more attention in recent years, due to the growing interest for reducing environmental pollution caused by plastics, the need to extend the shelf life of foods, and the increasing demand for healthier and ecological foods (Espino-Díaz et al., 2010).

Pectin is commercially produced from citrus peel as a by-product from extraction of lime, lemon and orange juices; or from apple pomace (Attila and William, 2009). Under certain circumstances, pectin forms gels; this property has made it a very important as edible coatings. Pectin coatings have been also studied for their ability to retard lipid migration and moisture loss, and to improve appearance and handling of foods (Ayranci and Tunc, 2004).

Chitosan is an edible and biodegradable polymer derived from chitin. Some desirable properties of chitosan are that it forms films without the addition of additives. It has been successfully used in many postharvest aspects of fruit and vegetables (Youwei and Yinzhe, 2013). Therefore, the aim of this work was to determine combined effects of optimum harvesting stage and edible coating material for better fruit quality and extended storage life of tomato fruits.

MATERIALS AND METHODS

Experimental site

This experiment was conducted in Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), Department of Post-Harvest Management Laboratory, Jimma, Ethiopia, between May and June, 2014. During the study time, mean temperature and relative humidity inside the laboratory were 22°C±1 and 74.5%±1, respectively.

Experimental material

Tomato fruits ((*Lycopersicon esculentum* Mill.) fresh type, variety Barbados at different stages of maturity were collected from Jitu Hawassa farm and transported to JUCAVM, Postharvest Management Laboratory. Maximum care was taken to minimize mechanical damage during harvesting, transportation and handling.

Preparation of experimental material

Fruit maturation level was precisely selected and the fruit color was compared in the field using biological color chart of USDA (1991). Harvesting was carried out manually in the morning and uniform shape and size fruits without any injuries or defects were selected. Harvesting stages were mature green (tomato surface is completely green), turning (tannish-yellow, pink or red color showed on over 10%, but not more than 30% of the tomato surface) and light red (pinkish-red or red color showed on over 60%, but red color covers not more than 90% of the tomato surface) (Figure 1). From each stage of maturity for each treatment, 18 uniform sized fruits were washed again with tap water containing 2% (w/v) sodium hypochlorite solution, and rinsed with sterile water, bloated using cheese cloth and left dried at ambient air condition.

Preparation and application of edible coating materials

Preparation of pectin solution

Commercially, available pectin (30 g) with 50% Degree of Esterification was dissolved in 1000 ml warm water (40°C), whilst stirred with magnetic stirrer to prepare 3% (w/v) pectin solution and allowed to homogenized with moderate stirring until the solute completely dissolved, as indicated in Felix and Mahendran (2009).

Figure 1. The three harvesting stages of tomato fruits used in the experiment.

Preparation of chitosan solution

The chitosan solutions were prepared according to El Ghaouth et al. (1992). An amount of 20 g chitosan was dispersed in 900 ml of distilled water to which 50 ml of glacial acetic acid was added to dissolve the chitosan. The solutions were centrifuged to remove undissolved particles. In order to guarantee the stability of the emulsions, the pH value was adjusted to 5.6 with 1N NaOH. Tween 80 (0.l% v/v) was added to the solutions to improve wettability of the solution during coating.

Application of coating materials

Fruits were uniformly dipped for 2 to 3 min in each solution when the temperature of the solutions reached at room temperature (25°C). Meanwhile control fruits were dipped in distilled water for the same duration and excess water/solution from the fruits were removed and air dried for 3 h at room temperature. A dry layer with plastic texture and general appearance of the fruits were used as criteria to determine the end of surface drying. Surface dried coated fruits were then packed in cardboard boxes with a size of 12 cm L × 10 cm H × 8.5 cm W having 6 openings of each with 7 cm^3 size on four sides (except bottom and top parts). The data were recorded before treatment (day 0) and in 5 days interval for all physicochemical parameters for 20 days.

Data collected

Data were collected for both physical, disease and chemical parameters. First, the non distractive parameters were measured then, the distractive measurements were taken.

Physiological weight loss

The weight losses of fruits were recorded on day zero treatment through storage time under ambient storage conditions and then it was recorded in every 5 days intervals. Relative percentage weight loss was calculated using Equation 1 and the cumulative weight loss was expressed as the cumulative percentage for the respective treatments (Athmaselvi et al., 2013).

$$WL\ (\%) = \frac{WI - WF}{WI} \text{ X } 100\% \quad (1)$$

where WL *(*%) = percentage physiological weight loss, *WI*=initial fruit weight in g, and *WF*=final fruit weight in g at the indicated period.

Fruit firmness

The method indicated in Fan et al. (1999) was used to determine fruit firmness using Texture Analyzer (TA-XT plus, UK). The force required for the plunger to press into the fruit was recorded and expressed in Newton. Stable Microsystems with 2 mm plunger tip, with flat head stainless-steel cylindrical probe was used to measure tomato fruit firmness. For the current study from each treatment two fruits were used at a time and the average result was used for the analysis. The start of penetration test was the contact of the probe on tomato surface and finished when the probe penetrated the tissues to depth of 5 mm with the probe speed of 1.5 mm/s. The point where the maximum force measured at time of penetration was recorded as the maximum value to determine fruit firmness and expressed in Newton.

Total color change

Total colour change of samples were determined using Commission Internationale de L'Eclairage (CIE) L*a*b* color space to evaluate the effect of coating on color change of samples using tri-stimulus colorimeter (Accu probe HH06), which was calibrated with white tile (L=83.14, a*=-3.67 and b*=10.79). Total color change were expressed in terms of "L*" value, lightness ranging from zero (black) to 100 (white), "a*" (redness) value and "b*" (yellowness) value. Color measurement was made on day zero and when data were collected on specified day intervals. Fruit colors on day zero were considered a target sample color and color changes were evaluated as compared to day zero color. Multiple readings (5 times) per fruit were taken from each sample by changing the position of the tomato fruits to get representative color measurements (Maftoonazad and Ramaswamy, 2005). The total color change (ΔE) was calculated using Equation 2.

$$\Delta E = \sqrt{(L^* - L)^2 + (a^* - a)^2 + (b^* - b)^2} \quad (2)$$

where ΔE is represents the total color change as compared to raw; L^* and L are initial and final lightness values, respectively; a^* and a are initial and final redness values, respectively; b^* and b are initial and final yellowness values, respectively.

Disease incidence

Disease incidence was calculated as number of infested fruits showing any disease symptoms out of the total numbers of tomato fruits stored. Five separate tomato fruits were allocated and used for disease incidence and percent disease index evaluation were performed according to Hossain et al. (2010) (Equation 3).

$$Disease\ incidence\ (I)(Frequency) = \frac{Number\ of\ fruits\ infected}{Total\ number\ of\ fruits\ assesed} \times 100 \quad (3)$$

Determination of shelf life of stored fruits

The shelf life of tomatoes were calculated by counting the days required for them to attain the last stage of ripening, but up to the stage when they remained still acceptable for commercial marketing. About 10% physiological loss in weight was considered as an index of termination of the shelf life (threshold level) of fruit commodities (Pal et al., 1997; Acedo, 1997).

Determination of pH and titratable acidity (TA)

The fruits were crushed and made into pulp juice, and used to measure the pH using calibrated digital pH meter (CP-505). TA (expressed as % citric acid) was determined by titration (AOAC, 2000). From the juice 5 ml was taken and added in to 250 ml conical flask. Then 10 ml of water was added to make the fruit color light to facilitate clear end point detection. To determine the total TA of the pulp, fresh 0.1 N NaOH was used. TA of tomatoes expressed as percentage of citric acid using Equation 4.

$$\%\ Acid = \frac{(ml\ NaOH)(No.\ of\ the\ base\ in\ mol\ per\ liter)(0.0064)}{Sample\ volume\ in\ ml} \times 100 \quad (4)$$

where 1 ml 0.1N NaOH is equivalent to 0.0064 g citric acid.

Determination of TSS

TSS content of tomato fruit pulp was determined using hand held digital refractometer (DR 201-95). The percentage of TSS was obtained from direct reading of the refractometer in °Brix after taking the required temperature correction values. Multiple measurements (3 to 5) were taken per a treatment and the average values were used for analysis.

Determination of TSS/TA ratio (TSS:TA)

The ratio between total soluble solids and titratable acidity was determined by dividing the TSS to that of TA in order to have a sugar-acid balance of samples for each treatment. To calculate the amount of sugar acid ratio, Equation 5 was used:

$$sugar\ acid\ ratio = \frac{{}^{o}brix\ value}{percentage\ acid} \quad (5)$$

Determination of ascorbic acid content

Ascorbic acid content was determined by spectrophotometric method (Mohammed et al., 2009). Five grams of tomato sample was mixed with 100 ml of 6% trichloro acetic acid and transferred into a 200 ml volumetric flask and shaken gently to homogenize the solution. The obtained solution was filtered and centrifuged at 4000 rpm for 15 min, and then the sample transferred to a conical flask and 1 to 2 drops of saturated bromine solution was added and aerated, and to each 10 ml aliquot 10 ml of 2% thiourea was added. From 10 ml of aliquot, 4 ml was added into each of test tubes, then 1 ml of 2, 4-DNPH solution was added to form osazone. DNPH reacts with ketone groups of dehydroascorbic acid under acidic conditions to form a red osazone derivative. All samples and blank solution were kept at 37°C for 3 h in a thermostatic hot water bath (WB-8B, China). After all samples were cooled in an ice-water mix for 30 min then treated with 5 ml chilled 85% H_2SO_4, with constant stirring. Finally, a colored solution absorbance was measured at 521 nm using spectrophotometer (T80 UV/VIS spectrophotometer, UK) and concentration of vitamin C was estimated using Equation 6.

$$mg\ AA/100g = \frac{[(As - Ab) \times 10]}{[A10\mu g\ std - Ab]} \quad (6)$$

where A_s = Absorbance of samples; A_b=Absorbance of blank; $A_{10\ \mu g\ Std}$=Absorbance of 10 µg AA standard.

Estimation of lycopene content

The lycopene content of the fruits were analyzed according to the method described in Nagata and Yamashita (1992). Briefly, first fruits were crushed and well homogenized, seeds were separated and then one gram of the sample (tomato pulp) was taken. All pigments in the sample were extracted by acetone and hexane (4:6). The samples were well homogenized using homogenizer to extract all pigments in the fruit. After homogenization samples were placed to a beaker and allowed to stand for about 15 min so that there was a clear pigment in a layer of the extractors (acetone and hexane). Finally, the pigments from top part were collected with quartz curvet (10 mm path length) and their (5) absorbance were measured using spectrophotometer's (T80 UV/VIS, UK) at different wave lengths (663, 645, 505 and 453 nm). Wave lengths measured were used to estimate total lycopene content using Equation 7 as indicated in Nagata and Yamashita (1992):

$$Lycopene\ \left(mg/100g\right) = -0.0458A_{663} + 0.204A_{645} + 0.372A_{505} - 0.0806A_{453} \quad (7)$$

where A_{663}, A_{505} and A_{453}, are absorbencies at 663, 505 and 453 nm

Determination total phenolic content

Total phenols were measured spectrophotometrically using Folin-Ciocalteu reagent with gallic acid as a standard (Gao et al., 2011). Briefly, 50 µl of tomato extract were added to 3 ml of deionized water plus 250 µl of Folin-Ciocalteu reagent (1N). After a 5 min reaction time, 750 µl of 20% Na_2CO_3 solution was added. The mixture volume was made up to 5 ml with deionized water. Then, the total phenolic content was measured at 760 nm after a 30 min reaction time using spectrophotometer (T80 UV/VIS, UK). The results are reported in terms of mg of gallic acid equivalent (GAE) per 100 g of fresh weight. Pure Gallic acid (GA) was used as a standard (covering the concentration range between 0.1 and 1.0 mg/ml) (R^2 = 0.993) and results were expressed as milligrams of GAE per gram of fresh weight.

Design of the experiment and data analysis

In this study, all the experiments were laid in a Completely Randomized Design (CRD) with a factorial treatment combination, replicated three times, whereby 18 tomato fruits were used per replication.

Significance of treatment effects were evaluated by analysis of variance model using SAS statistical program (Version 9.2) and the mean of the variables whenever significantly different for main or interaction effects, comparisons were made using Tukey's test at 5% significance level. Data for disease incidence and severity were analyzed using non parametric test.

RESULTS AND DISCUSSION

Physiological weight loss (PWL)

Weight loss is an important index of postharvest storage life in fresh produces. It is mainly attributed to the loss of water during metabolic processes like respiration and transpiration. Both processes are affected by storage environment of the fruit and the loss in weight is an indicator how the product is handled and stored. Because of this, physiological weight loss appeared to be the major detrimental factor of storage life and quality of tomato fruits in particular and horticultural crops in general.

Weight loss of perishable crops has economical implication, a loss in moisture results in loss in weight of product to be sold. In this regard, maturity stage at harvest and coating material showed significant ($P<0.05$) interaction effect in terms of weight loss reduction as compared to control with extended storage time. For instance pectin and chitosan films coated fruits showed less weight loss in green mature and turning stages than fruits harvested at light red stage (Table 1). This result is in line with Getinet et al. (2008) who reported that the highest weight loss was recorded in Marglobe tomato fruits harvested at light-red stage and the lowest was from Roma VF variety harvested at mature-green stage. However, a significant weight loss was observed from mature green uncoated fruits than coated ones at light red stage.

When combined effects are compared, fruits harvested at turning stage and coated with pectin or chitosan film showed lowest loss at 15th and 20th days of storage. But with an increase in storage time, weight loss progressively increased in different rate with the presence or absence of coating films.

Moisture loss and gaseous exchange from fruits is usually controlled by the epidermal layers provided with guard cells and stomata. The film formed on the surface of the fruit act as a physical barrier to reduce moisture migration from the fruits (Togrul and Arslan, 2004). This barrier property also reduces the oxygen availability and uptake by the fruit for respiration process and hence slows down rate of respiration and associated weight (Abbasi et al., 2009).

Fruit firmness

Fruit firmness is a major attribute that dictates the postharvest life and quality of fruits. It is associated to the susceptibility of tomato fruit cell walls to different postharvest handling factors. Firmness of the fruits was better preserved by the application of coatings as seen in Figure 2. The study revealed a significant ($P < 0.01$) interaction effect between coatings and maturity stages on fruits firmness. Firmnesses of fruits before coating were 9.01, 7.47 and 6.3 N for mature green, turning stage and light red fruits, respectively. The variation is due to the strength of cell wall of fruits at different harvesting stage. However, better firmness values were maintained on coated fruits than uncoated ones (Figure 2). At the end of 15th day storage, uncoated fruits clearly showed the lowest firmness and went to deterioration and discarded. The loss shows that loss in firmness of fruits can be slowed down with the application of coating film, particularly when combined with mature green stage of harvesting as compared to control fruits. In a similar study, Tilahun (2013) showed that the highest values of firmness for mature green fruits than at full ripen stage.

Maftoonazad and Ramaswamy (2008) also indicated that as the length of storage period extended, uncoated peach fruits showed a significant decrease in firmness, while loss of texture and softening were delayed in coated fruits. In their former work, Maftoonazad and Ramaswamy (2005) reported that firmness value in coated samples was almost 1.5 times higher than that of uncoated fruits, as reported for avocados coated with methylcellulose. Similarly, Chauhan et al. (2013) indicated that Shellac based surface coating retained tomatoes' firmness better than control fruits. Delay in loss of cell wall firmness might be associated with limited availability of oxygen from the ambient atmosphere for respiration process and subsequent delay on cell wall degradation. Generally, the combined treatment effect of coating and early harvesting stage showed beneficial effect on firmness retention as compared to uncoated fruits for distant market shipment. Even though coating materials showed significant interaction effects, but relatively better fruit firmness was observed when pectin coating combined with green mature stage (after 5 and 10 days storage) and turning stage (after 20 days storage). This might be due to storage stability of pectin coating on fruits surface as compared to chitosan film.

Total fruits color change

Color is a very important indicator of ripening and determinant of quality and consumer acceptability. The total color difference (ΔE) extensively used to determine ripening due to chlorophyll degradation and formation of lycopene. It is apparent that tomato fruits harvested at different stages of maturity exhibit color difference.

However, for comparison purpose, original fruit color immediately after coating was taken as a bench mark color to evaluate color changes of fruits. Compared to

Table 1. Effects of pectin and chitosan coatings on physiological weight loss (%) of tomato fruits harvested at different stages of maturity.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control (uncoated)	Mature green	3.4[cd]	10.0[c]	14.0[c]	-
	Turning stage	3.8[c]	11.1[b]	15.8[b]	-
	Light red	5.3[a]	13.3[a]	18.7[a]	-
Chitosan	Mature green	3.0[e]	6.97[f]	10.2[de]	14.5[c]
	Turning stage	3.4[d]	8.1[e]	9.5[e]	13.5[d]
	Light red	4.3[b]	9.1[d]	11.0[d]	17.4[a]
Pectin	Mature green	2.9[e]	6.7[f]	9.5[e]	14.7[c]
	Turning stage	3.7[cd]	8.1[e]	8.5[f]	13.0[d]
	Light red	4.3[b]	9.0[d]	10.9[d]	15.8[b]
LSD (5%)	-	0.4	0.6	0.8	0.6
CV (%)	-	6.4	4.2	4.3	2.5

*After 15 day of storage all control fruits were spoiled and discarded; Means followed with the same letter (s) within a column are not significantly different ($p<0.05$).

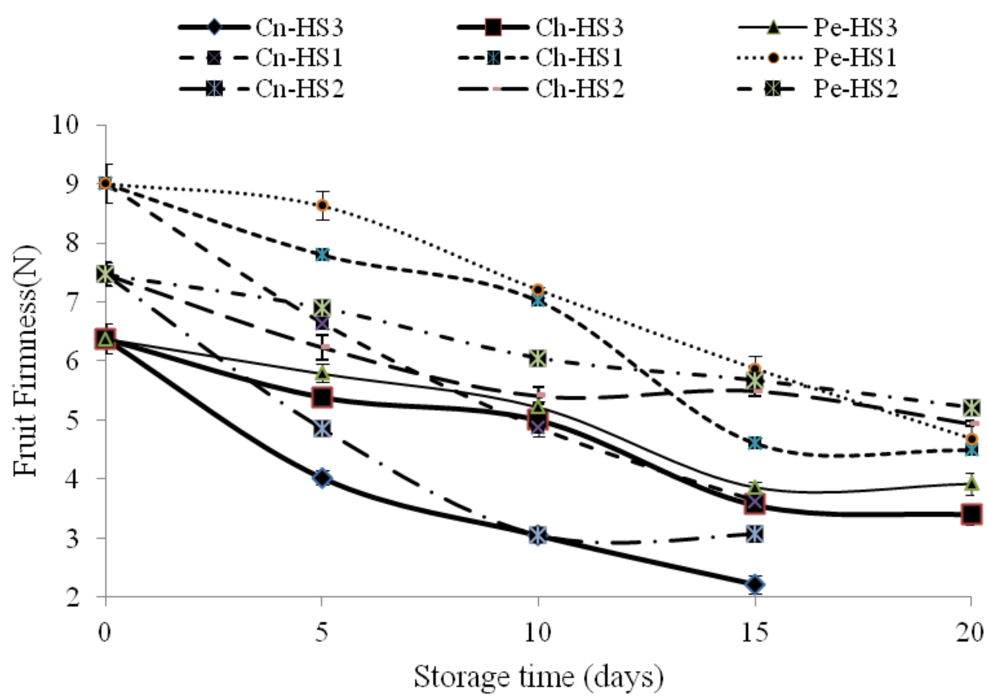

Figure 2. Fruit firmness of coated and control tomato fruits harvested at different maturity stages and stored at ambient temperature condition. Cn-HS1 = Uncoated Mature Green, Cn-HS2= Uncoated Turning, Cn-HS3 = Uncoated Red; Ch-HS1= Chitosan coated Mature Green, Ch-HS2= Chitosan coated Turning, Ch-HS3 = Chitosan coated Red; Pe-HS1= Pectine coated Mature Green, Pe-HS2 = Pectine coated Turning, Pe-HS3 = Pectine coated Red.

initial color of fruits, coated fruits showed significant delay on change of color as compared to uncoated ones. Figure 3 shows progressive change of total color change with time from initial values as affected by types of coating materials and maturity stage at harvesting. There was a fast color development from uncoated fruits and become fully turn to red within 2 to 5 days as compared to chitosan and pectin coated fruits (5 to 12 days)

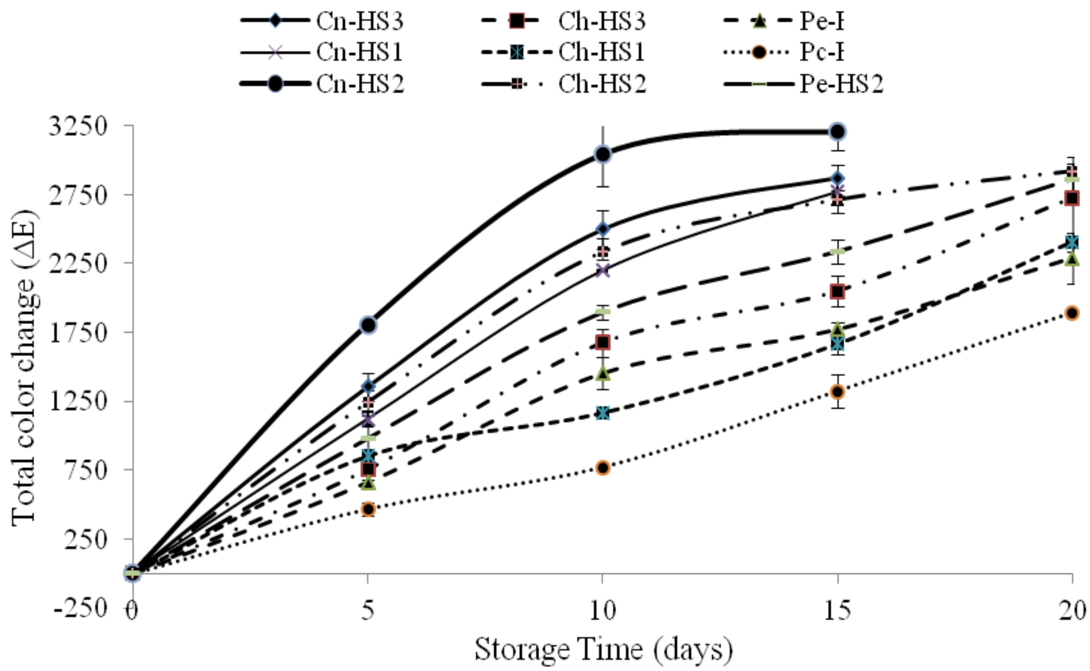

Figure 3. The effects of fruit coating materials on total color change of tomato fruits harvested at different stage and stored under ambient condition. Cn-HS1= Uncoated Mature Green, Cn-HS2= Uncoated Turning, Cn-HS3= Uncoated Red; Ch-HS1= Chitosan coated Mature Green, Ch-HS2= Chitosan coated Turning, Ch-HS3= Chitosan coated Red; Pe-HS1= Pectine coated Mature Green, Pe-HS2= Pectine coated Turning, Pe-HS3= Pectine coated Red.

depending upon stage of maturity. Similar results were also indicated in Ali et al. (2011), a retardation of color development in papaya fruits coated with higher concentrations of chitosan due to slow rate of respiration and reduced ethylene production. This, in turn, delayed the ripening and senescence of the fruits, resulting in reduced color change. Elevated CO_2 levels (>1%) in fruit tissues (which could be achieved by coating materials) might have been shown to retard fruit ripening by inhibiting ethylene synthesis (Martínez-Romero et al., 2007; Zapata et al., 2008).

Disease incidence (%)

Results in Table 2 indicate that percent incidence of diseases was significantly (P<0.05) affected by the interaction effect of coating and harvest stages. The incidence was significantly lower on coated tomato fruits as compared with uncoated ones. On the control, fruits harvested at light red stage (more ripen fruits) the first disease occurrence was observed on the 5th day of storage which was 6.7% and as the fruit become ripen they became more susceptible to fungal contamination and exhibited a 100% incidence.

On other hand, after 15th day of storage at ambient conditions the disease incidence on mature green fruits of control, chitosan and pectin coated fruits were 53.33, 26.6 and 6.6%, respectively. Abbasi et al. (2009) also observed that the decay control of irradiated chitosan coated mango fruit as compared to uncoated ones. El-Ghaouth et al. (1991) suggested that chitosan induces chitinase, a defense enzyme, which catalyzes hydrolysis of chitin, a common component of fungal cell walls, thus preventing the growth of fungi on the fruit. Similarly, Zhang et al. (2011) stated that Chitosan could effectively inhibit postharvest diseases of fruits by direct inhibition of spore germination, germ tube elongation and mycelial growth of phytopathogens as well indirect inducement of defense-related enzymes. Antimicrobial capacity of edible coating materials also reported for gum Arabic. Fruits treated with 10% gum arabic coating remained disease free even after 20 days of storage. Many of the control fruits (67%) were spoiled after 16 days of storage (Ali et al., 2010).

As indicated in the earlier sections, application of coating delayed the rate of firmness lose due to preserving cell wall integrity. Furthermore, coating can reduce rate of respiration and ethylene synthesis. These conditions in combination could assist cell wall to retain more integrity against fungal attack (Hassan et al., 2014). Furthermore, coating helps to delay senescence, which makes the commodity more vulnerable to pathogenic infection as a result of loss of cellular or tissue integrity

Table 2. Effect of coating materials during storage on disease incidence of tomato fruits harvested at different maturity stages.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control(uncoated)	Mature green	0.0[b]	6.7[c]	53. 3[c]	-
	Turning stage	0.0[b]	33.3[b]	80.0[b]	-
	Light red	6.7[a]	53.3[a]	100[a]	-
Chitosan	Mature green	0.0[b]	0.0[c]	26. 7[de]	33. 7[bc]
	Turning stage	0.0[b]	0.0[c]	33. 3[de]	40.0[ab]
	Light red	0.0[b]	13.3[c]	40. 0[cd]	53. 3[a]
Pectin	Mature green	0.0[b]	0.0[c]	6.7[f]	11.4[d]
	Turning stage	0.0[b]	0.0[c]	20. 0[ef]	31.4[cd]
	Light red	0.0[b]	6.7[c]	33. 3[de]	40.0[ab]
CV	-	0.4	0.4	0.35	0.2
LSD (5%)	-	3.8	2.9	5	5.7

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different.

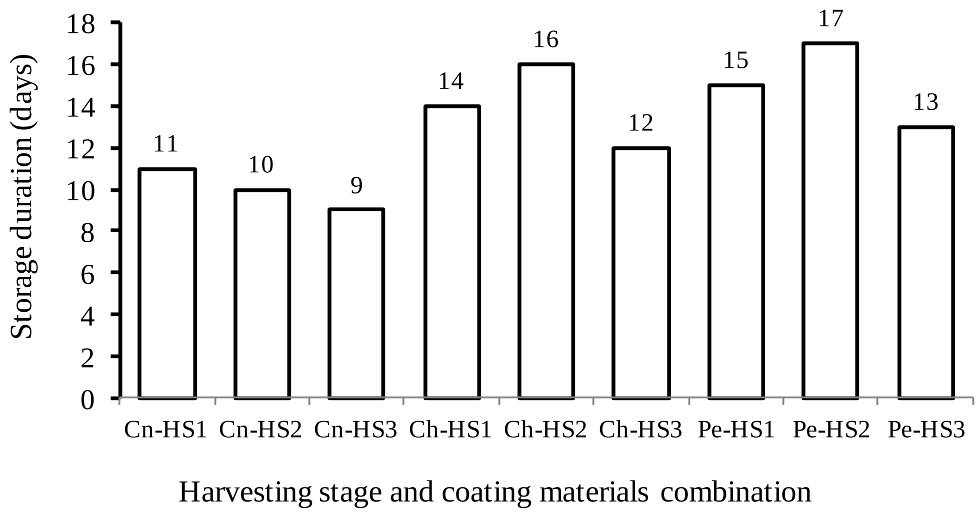

Figure 4. Shelf life (days) of tomato fruits harvested at different maturity stages and coated with pectin and chitosan films. Cn-HS1= Uncoated Mature Green, Cn-HS2= Uncoated Turning, Cn-HS3= Uncoated Red; Ch-HS1= Chitosan coated Mature Green, Ch-HS2= Chitosan coated Turning, Ch-HS3= Chitosan coated Red; Pe-HS1= Pectine coated Mature Green, Pe-HS2= Pectine coated Turning, Pe-HS3= Pectine coated Red.

(Tanada-Palmu and Grosso, 2005).

Shelf life (days)

Shelf life implies time period, whereby a product is not only safe to eat, but still has acceptable taste, texture and appearance after being removed from its natural environment (Nieto, 2009). The shelf life of tomato fruits was considerably influenced by the coating and harvesting stages at maturity. In the present study, tomato fruits were decayed within 10 to 20 days of storage after harvesting. As shown in Figure 4, maximum shelf life was observed for tomatoes fruits harvested at turning stage coated by pectin (17 days) and chitosan (16 days) films. However, minimum shelf life was for control

Table 3. Effect of coating with pectin and chitosan and stage of maturity at harvest on pH of tomato fruit pulp during storage under ambient condition.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control (uncoated)	Mature green	4.10[e]	4.38[d]	4.53[d]	-
	Turning stage	4.27[c]	4.49[bc]	4.76[b]	-
	Light red	4.40[a]	4.63[a]	4.85[a]	-
Chitosan	Mature green	4.07[ef]	4.24[f]	4.38[f]	4.41[d]
	Turning stage	4.19[d]	4.38[d]	4.45[e]	4.64[b]
	Light red	4.36[ab]	4.52[b]	4.6[c]	4.74[a]
Pectin	Mature green	4.03[f]	4.26[f]	4.29[g]	4.38[d]
	Turning stage	4.16[d]	4.33[e]	4.39[ef]	4.5[c]
	Light red	4.33[b]	4.49[c]	4.53[d]	4.64[b]
LSD (5%)	-	0.04	0.02	0.06	0.11
CV (%)	-	0.6	0.3	0.7	0.5

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different.

tomatoes harvested at light red stage (9 days). For tomatoes harvested at light red stage coated with pectin had a maximum marketable storage life of 13 days followed by chitosan (12 days). Similarly, Maftoonazad and Ramaswamy (2008) also used a pectin-based composite coating on avocados and evaluated the extent of quality changes under different storage temperatures for predicting the quality loss. Their results showed that pectin-based composite coatings significantly reduced the rate of physical, chemical and physiological changes in avocados during storage and extended the storage life by more than a month at 10°C storage. Felix and Mahendran (2009) in their study showed that coated red tomatoes fruits took 15 days to ripe at 30°C, whereas the uncoated ones ripen within 5 days.

pH of fruit pulp

The pH of tomatoes is determined primarily by the acid content of the fruit that determine the product safety. In general, with an increase on days of storage and harvesting stages regardless of coating materials, pH of samples was showed an increase in value. Borji and Jafarpour (2012) and Moneruzzaman et al. (2009) also indicated that the pH of tomato fruit increased with advancement in maturity stage from mature-green to full-ripe stage. Significant ($P < 0.05$) difference in pH value of tomato fruit was observed due to the interaction effect of maturity stages and coating. The lowest pH values after 15 days of storage were observed for fruits coated with pectin at different stages of harvesting, whereas the highest for uncoated ones (Table 3). A decrease in pH values associated with a decrease in titratable acidity of the fruits and the higher acidity in coated fruits might be because of reduced respiration rate due to limited availability of oxygen (Jiang and Li, 2001). Athmaselvi et al. (2013) also reported that, aloe vera treated tomato fruits were better in keeping pH and showed a better effect in comparison with untreated fruit. The same effect was also reported in Maftoonazad and Ramaswamy (2005), the pH of peache fruits increased at a higher rate in control samples as compared to coated fruits.

Titratable acidity (TA)

The acidity of tomato plays a major role and imparts taste to the fruits. TA is an important consumer variable as the balance of TSS and TA relates to overall taste and consumer acceptability. The TA values of coated and uncoated fruits decreased with storage time (Table 4) and the value was significantly higher ($P \leq 0.05$) in chitosan and pectin treated fruits compared to the control due to the interaction effect of maturity stages and coating materials. In coated fruits harvested at turning and mature green stage, TA increased and peaked after 5 days of storage and showed a decline in concentration. Getinet et al. (2008) indicated that higher value in TA (0.67%) in fruits harvested at turning stage and the lowest value (0.58%) was from fruits harvested at mature green stage. On 15th day of storage, the highest TA values were observed for fruits harvested at turning stage but coated with Chitosan and pectin. The values were almost double of that of uncoated fruits harvested at the same maturity stage. This confirms that edible coating materials reduce the rate of acid metabolism (Yaman and Bayoindirli, 2002) as compared to control. Since organic

Table 4. Effect of coating with pectin and chitosan and stage of maturity at harvest on titratable acidity (%) of tomato fruits.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control (uncoated)	Mature green	0.36[d]	0.28[c]	0.19[c]	-
	Turning stage	0.42[b]	0.24[d]	0.14[d]	-
	Light red	0.23[f]	0.14[f]	0.087[e]	-
Chitosan	Mature green	0.39[c]	0.36[b]	0.28[b]	0.24[b]
	Turning stage	0.45[a]	0.34[b]	0.33[a]	0.19[c]
	Light red	0.29[e]	0.21[e]	0.18[c]	0.16[d]
Pectin	Mature green	0.41[b]	0.40[a]	0.27[b]	0.27[a]
	Turning stage	0.47[a]	0.36[b]	0.31[a]	0.22[b]
	Light red	0.31[e]	0.28[c]	0.25[b]	0.18[c]
-LSD (5%)	-	0.024	0.020	0.028	0.025
CV (%)	-	3.8	4.0	7.3	6.5

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different.

acids, such as malic or citric acid, are primary substrates for respiration, a reduction in acidity is expected in terms of rate of increase in respiration of cells of fruits (El-Anany et al., 2009). The decreasing acidity at the end of storage might be due to use of the acids as energy source with an increase in ripening (Wills et al., 1998; Castro et al., 2005). In another study, Abassi et al. (2009) reported that chitosan coatings slowed the changes on TA of mango, but on control fruits the rate of decline were significantly higher. Result of this study is also in agreement with Ali et al. (2010) who analyzed the effects of gum arabic as an edible coating for preservation of TA in tomato fruit.

Total soluble solids (TSS)

TSS is an important factor to be considered with respect to consumer acceptance. It is expected to increase during ripening and decrease towards senescence (Tasdelen and Bayindirli, 1998). It has been reported that TSS increases with stage of ripeness at harvest (Znidarcic and Pozrl, 2006) and also it generally increases with advancement in maturity during storage (Getinet et al., 2008) which is in agreement with the current result. In the present study, it was observed that a significant ($P < 0.05$) interaction effect between coating and maturity stages. TSS of control fruits at the end of the storage period (15th day) was 4.8, 4.6, and 4.2 °Brix for fruits harvested at mature green, turning and light red stages, respectively. Borji and Jafarpour (2012) noted that, maturity stages at harvest could affect the TSS content of the fruit. The authors found that the TSS content of mature green and full ripe tomatoes was 5.1 and 6.2 °Brix, respectively. Whereas tomato fruits coated with pectin resulted in 4.9, 5.4 and 4.9 °Brix and that of chitosan coated having a 5.1, 5.5 and 5 °Brix for the same stage of harvesting, respectively. Similar results were also reported when mango fruits were coated with pectin (Moalemiyan et al*.,* 2012). In all cases, fruits harvested at turning stages showed relatively higher TSS values, which might be associated with, higher concentration of organic acid and soluble sugar balance as compared to early or late mature fruits at both stages of harvesting.

Coatings provide an excellent semi-permeable film around the fruit, modifying the internal atmosphere by reducing O_2 availability for respiration and degradation of macromolecules. Decreased respiration rates slow down the synthesis and use of metabolites resulting in slower rate of increase on TSS (Yaman and Bayoindirli, 2002). The decrease in TSS is caused by a decline in the amount of carbohydrates and pectins, partial hydrolysis of protein and decomposition of glycosides into sub-units during respiration causing a decrease in TSS (Athmaselvi et al., 2013; Moalemiyan et al*.,* 2012).

TSS/TA ratio as a maturity index

The TSS/TA ratio is an important factor for quality parameters of tomato fruits, since it is known that sweetness and sourness are important criteria for tomato flavour (Stevens et al., 1995). The relationship TSS and TA which could be taken as maturity ripening index (RI) showed a significant differences ($P<0.05$) as a function of maturity stage, coating and their interaction. The TSS/TA ratio increased significantly along with increased storage time in both uncoated and coated fruits (Table 5). TSS/TA at green stage for control, pectin and chitosan

Table 5. Effect of treatment with pectin and chitosan at different harvesting stage on total soluble solids (°Brix) of tomato fruit.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control (uncoated)	Mature green	3.7[e]	4.5[d]	4.8[c]	-
	Turning	4.4[c]	5.1[ab]	4.6[d]	-
	Light red	5.1[a]	4.9[b]	4.2[e]	-
Chitosan	Mature green	3.3[f]	4.4[d]	4.9[c]	4.4[c]
	Turning	4.2[d]	4.9[b]	5.4[a]	4.8[ab]
	Light red	4.8[b]	5.2[a]	4.9[c]	4.5**c**
Pectin	Mature green	3.2[f]	4.1[e]	5.1[b]	4.6[c]
	Turning	4.2[d]	4.7[c]	5.5[a]	5.1[a]
	Light red	4.6[c]	5.2[a]	5.0[bc]	4.7[bc]
LSD	-	0.21	0.16	0.22	0.23
CV%	-	3	2.0	2.5	2.8

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different

Table 6. TSS/TA ratio for control, pectin and chitosan coated fruits harvested at different maturity stages and stored at ambient condition.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control (uncoated)	Mature green	10.0[de]	16.1[d]	25.6[c]	-
	Turning stage	10.6[d]	20.8[c]	32.7[b]	-
	Light red	22.0[a]	36.0[a]	49.4[a]	-
Chitosan	Mature green	8.5[f]	12.3[ef]	19.3[d]	18.4[d]
	Turning stage	9.4[f]	14.5[de]	17. 6[d]	25.0[b]
	Light red	17.0[b]	24.5[b]	27.7[c]	29.1[a]
Pectin	Mature green	7.9[f]	10.3[f]	19.1[d]	16.8[d]
	Turning	8.8[f]	13.1[e]	16.6[d]	21. 1[c]
	Light red	15.1[c]	19.1[d]	19.8[d]	24.8[b]
LSD	-	1.49	2.52	4.42	2.54
CV%	-	7.2	7.9	10.2	6.4

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different.

treated fruits at day 5 was 10.09, 8.52, and 7.91, respectively and subsequently reached to 25.65, 17.57, and 19.10 by the end of the storage period with a significant interaction effect between maturity stages and coatings. Generally, coated tomato fruits revealed relatively small ratio changes for all harvesting stages (Table 6). Similar results were also reported in Al-Mughrabi (1994) who demonstrated that harvesting at mature-green stage had lower TSS/TA ratio values in comparison with red-ripe fruits. In general from result of this study, a ratio above 10 can be used as index to determine degree of ripeness of tomato fruits. For instance, uncoated fruit at light red harvesting stage of 5th day of storage showed almost equivalent ratio for coated samples at 15th day of storage. As index of ripening, the ratio can be used to investigate the positive effect of coating materials on preserving of total soluble compounds in fruits as compared to uncoated ones.

Ascorbic acid content

Table 7 shows the changes in the ascorbic acid content of tomato fruits at three maturity stages, treated with chitosan and pectin in 20 days of storage time at ambient temperature. Significant differences were observed

Table 7. Changes in ascorbic acid (mg/ 100 g) of tomato fruits harvested at three maturity stages, coated with pectin and chitosan and stored at ambient temperature.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control (uncoated)	Mature green	14.6^{d}	16.7^{e}	17.9^{f}	-
	Turning stage	31.6^{a}	29.6^{b}	15.8^{g}	-
	Light red	21.0^{c}	14.6^{f}	13.0^{h}	-
Chitosan	Mature green	9.6^{egf}	20.0^{d}	30.5^{c}	21.1^{d}
	Turning stage	12.9^{de}	34.7^{a}	34.3^{b}	27.1^{b}
	Light red	23.5^{b}	25.5^{c}	22.2^{e}	15.7^{f}
Pectin	Mature green	8.3^{g}	26.3^{c}	30.1^{c}	22.6^{c}
	Turning stage	11.2^{def}	31.0^{b}	38.0^{a}	29.1^{a}
	Light red	21.0^{c}	30.1^{b}	26.7^{d}	18.3^{e}
LSD (5%)	-	1.87	1.63	1.72	1.41
CV (%)	-	4.9	3.6	3.9	3.6

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different.

among treatments (P<0.05) for their interaction. For fruits at turning stage, the mean value of ascorbic acid content was 15.80, 34.38 and 38.08 mg/100 g fresh weights for control, chitosan and pectin, respectively (on 15th day after coating). Green mature fruits showed ascorbic acid values of 17.94, 30.60, and 30.10 mg/100 g fresh weight for control, chitosan, and pectin treatments for the same duration of storage. However, light red tomatoes showed ascorbic acid values of 13.03, 22.20, and 26.70 mg/100 g fresh weight for control, chitosan, and pectin treatments (on 15th day after coating). Sharma et al. (1996) reported ascorbic acid content ranged from 11.21 to 53.29 mg/100g in tomato genotypes which is in agreement with values indicated in this study. Similar results were also reported in Tigist et al. (2011) a general trend of increase in ascorbic acid content, followed by a falling during full ripening stage.

Results illustrated in Table 7 show a reduction in ascorbic acid content along with the storage period not only for coated fruits but also for the control. However, a decrease in ascorbic acid content was significantly higher in control as compared with coated fruits. High ascorbic acid in coated fruits could be attributed with slow ripening rate due to semi-permeable membrane films of chitosan and pectin, since coatings serve as a protective layer and control for the diffusion of O_2 (Srinivasa et al., 2006) which is critical to initiate respiration processes (Ayranci and Tunc, 2004). Ali et al. (2010) reported a similar slow down of ascorbic acid degradation for gum Arabic coated tomato during ripening. Likewise Ali et al (2011) also reported papaya fruits coated with chitosan showed a slower initial increase in ascorbic acid as compared to uncoated fruits. This suggests that chitosan and pectin coatings slowed down the synthesis of ascorbic acid during ripening and also slowed down the rate of loss in coated fruits which can be attributed with O_2 availability for respiration and oxidation.

Lycopene content

Lycopene is the major carotenoid compound in tomatoes, it gives the fruit its characteristic red color (Frusciante et al., 2007). The lycopene content of tomatoes has been previously reported to be in the range of 0.88 to 4.2 mg/100 g of fresh weight (Clinton, 1999). During ripening, the chlorophyll content decreases, and there is a rapid synthesis of the red pigment lycopene. Table 8 shows the changes in the lycopene content of tomato fruits at three maturity stages coated with chitosan and pectin over 20 days of storage at ambient condition. In the current study, significant ($P < 0.05$) difference was observed on the lycopene content of tomato fruits due to the interaction effect of maturity stages and edible coating materials.

Generally, lycopene content of the tomato fruits increased with the storage time in all treated and untreated fruits (Table 8) which was associated with ripening stages. However, the content of untreated fruits increased sharply and reached to a maximum level after 15 days of storage. But similar lycopene concentration was noted from pectin and chitosan coated fruits on 20th day of storage. The ripening and antioxidant index of the tomatoes (lycopene) also varies from one ripening stage to the other and the variations were also observed with coated and uncoated fruits. The results of the study (Table 8) established that the content of lycopene from all

Table 8. Lycopene (mg/g) content versus time for control, pectin and chitosan coated samples harvested at different stages and stored at ambient condition.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	Day 10	Day 15	Day 20
Control (uncoated)	Mature green	0.22[c]	0.35[d]	0.81[c]	-
	Turning stage	0.27[b]	0.44[b]	0.88[b]	-
	Light red	0.30[a]	0.61[a]	0.95[a]	-
Chitosan	Mature green	0.14[e]	0.26[h]	0.42[f]	0.93[ab]
	Turning stage	0.19[d]	0.31[e]	0.51[e]	0.97[ab]
	Light red	0.27[b]	0.40[c]	0.59[d]	1.11[a]
Pectin	Mature green	0.11[f]	0.23[g]	0.37[g]	0.88[b]
	Turning stage	0.20[d]	0.28[f]	0.43[f]	0.94[ab]
	Light red	0.23[c]	0.39[c]	0.62[d]	1.05[a]
LSD (5%)	-	0.019	0.015	0.038	0.16
CV (%)	-	3.9	4.7	4.1	9.6

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different.

treatments increased with storage time but at different rates. The lowest concentration of lycopene (0.11 mg/100 g) was recorded in pectin coated fruits harvested at green stage after 5 days of storage while the highest concentration of 1.1 mg/100 g for chitosan coated fruits which were harvested at light red stage on 20th day after coating and of storage.

The early increase in lycopene content in control fruits might be due to faster ripening rate of fruits which leads to the conversion of chloroplasts to chromoplasts and lycopene accumulation in internal membrane system (Grierson and Kader, 1986). Results of this study is also in line with Ali et al. (2013) who reported that lycopene content of uncoated tomatoes increased sharply and reached to a maximum peak after 12 days of storage but those coated with gum arabic stayed for 16 days. It has also been reported that the formation of lycopene depends on the rate of respiration during storage (Javanmardi and Kubota, 2006). As indicated in earlier, coatings reduce rate of respiration of fruits through limiting O_2 availability. Since uncoated fruits exposed fully to atmospheric oxygen, the lycopene content of red light fruits after 15th days of storage was 0.95, 0.59 and 0.62 mg/100 g, for control, chitosan and pectin coatings.

Total phenolic content

Polyphenols are common constituents of foods of plant origin and are major antioxidants in the human diet. These compounds possess diverse biological properties which provide a number of benefits, including antioxidant, apoptotic, anti aging, anti carcinogenic and anti inflammatory activities, cardiovascular protection, and also inhibit angiogenesis and cell-proliferation (Han et al., 2007). In this study, significant ($P < 0.05$) difference on total phenolic content of tomato fruit was observed due to the interaction effect of maturity stages and coatings materials. After 10th day of storage, higher values of total phenolic content was observed on fruits harvested at turning stage but coated with pectin (93.2 mg/100 g sample) and followed by chitosan coated fruits (79.6 mg/100 g). The same trend was followed after 15 and 20th days of storage in terms of harvesting stages, but values were decreased when storage time increased to 20th day (Table 9). At this stage of harvesting, fruits could perceive coatings materials as a potential abiotic stress, thereby resulting in production of secondary metabolites like phenols in coated samples (González-Aguilar et al., 2010). The authors indicated that, edible coatings can produce abiotic stress on produce, modifying its metabolism and affecting the production of secondary metabolites such as phenolic and flavonoid compounds due to the oxidative stress created by coating. Previous studies also showed that low O_2 and elevated CO_2 concentrations increased the production of phenolic compounds during the storage of fresh cut melons, which was related to oxidative stress on the fruit (Frusciante et al., 2007). The accumulation of phenolic compounds may be promoted by PAL enzyme (Phenylalanine ammonia-lyase) activity, which is activated under stress conditions (Wu and Lin, 2002). In grapes treated with edible chitosan coatings, an increase in the PAL enzyme was also observed (Romanazzi et al., 2002).

Since phenolic compounds contribute to fruit quality in

Table 9. Total phenolic contents (mg/g) of tomato fruits harvested at different maturity stages and coated with pectin and chitosan films before storage at ambient condition.

Coating materials	Harvesting stages	Days after application of coating materials and stored at ambient condition mean temperature 22°C±1 and RH of 74.5%±1			
		Day 5	**Day 10**	**Day 15**	**Day 20**
Control (uncoated)	Mature green	56.0[e]	61.4[ef]	60.8 [f]	-
	Turning stage	69.8[c]	64.4[e]	50.2[g]	-
	Light red	64.9[d]	58.5[f]	44.3[h]	-
Chitosan	Mature green	52.4[f]	61.3[ef]	69.8[f]	57.5[e]
	Turning stage	67.3[cd]	79.6[b]	76.8[b]	70.8[b]
	Light red	75.8[b]	73.3[c]	68.0[d]	49.2[f]
Pectin	Mature green	47.0[g]	68.1[d]	73.9[e]	65.4[c]
	Turning stage	68.9[c]	92.3[a]	85.4[a]	79.0[a]
	Light red	79.1[a]	75.8[c]	70.7[c]	61.9[d]
LSD(5%)	-	0.030	0.032	0.025	0.018
CV	-	2.1	2.7	2.4	1.6

*After 15 day of storage all control fruits were spoiled and discarded; Means with the same letter (s) within a column are not significantly different.

terms of color, taste, aroma and flavor (Tomás-Barberán and Espín 2001), those coated fruits with higher phenolic content would have higher quality than controls. Furthermore, from health point of view, an increase in total phenolic content is related with the enhancement of antioxidant capacity (Reyes and Cisneros-Zevallos, 2003) of fruits. Similarly, Ali et al. (2010) reported the maximum amount of total phenolic content was observed on gum Arabic coated fruit and reached to a peak after 12 days of storaage and decreased sharply at the final days of storage.

Conclusions

Tomato is a highly perishable fruit that possesses a very short shelf life and reaches to respiration peak of ripening process in short period of time after harvesting. In view of easy adoption and sustainability of technologies, edible coatings can be a good alternative since they are simple, low-cost and environmentally friendly alternative technologies to extend postharvest life and reduce quality loss. The study showed that surface coating of tomato using pectin and chitosan solution can significantly (P< 0.05) delay changes in different quality attributes and the shelf life was extended during ambient storage as compared with uncoated fruits. Maximum shelf life was observed for tomatoes harvested at turning stage coated by pectin (17 days) followed by chitosan (16 days), and minimum shelf life was for uncoated fruits for the same harvesting stage (10 days). The most suitable stage for coating was turning stage for both chitosan and pectin to preserve better quality of tomato fruits. In the present experiment, coated fruits contain higher amount of ascorbic acid, lycopene and phenolic content. As both chitosan and pectin resulted in comparable effect, the choice of type of coating material depends on their price and availability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Wheat yield obtained from nitrogen dose and fractionation

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It is possible to increase nitrogen for wheat productivity by adjusting the single and fractionated dose based on the condition of the agricultural year. The objective of this work is to study the highest amount of nitrogen used for the production of wheat using single dose or fractionation under favorable and unfavorable cultivation years. The study was conducted in 2012, 2013 and 2014 in Augusto Pestana, Rio Grande do Sul, Brazil. The experimental design was a randomized block in a 4 × 3 factorial scheme with four replications. It consists of N-fertilizer rates (0, 30, 60 and 120 kg ha^{-1}), forms of supply [single (100%), growth stage V_3 (third expanded sheet); fractionated (70%/30%) growth stage V_3/V_6 (third and sixth expanded sheet); fractionated (70%/30%) phonological stage V_3/E (third expanded leaf and early grain filling)]. In favorable, intermediate and unfavorable years, wheat cultivated with single dose of nitrogen is more effective than the grain fractionated, regardless of the succession system. Nitrogen use efficiency can be substantially reduced or increased in wheat based on the condition of the year of cultivation and the use of the optimal dose of the nutrient may not necessarily express maximum grain yield with economic efficiency.

Key words: *Triticum aestivum,* relation C/N, meteorological condition, simulation.

INTRODUCTION

Wheat is one of the most produced cereals in the world. It has large derivatives and used for different types of flour (Stefen et al., 2015; Camponogara et al., 2016). Wheat is used in animal feed as bran, pastures and ensures soil

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coverage in no tillage farming (Rodrigues et al., 2014; Santos, 2016). Wheat cultivation extends from the South to the West Central of Brazil, which subjects the culture to different conditions of climate and soil, hindering stability in productivity (Costa et al., 2013; Chavarria et al., 2015). The high productivity and quality of grain wheat is associated with the performance of cultivars, management technologies, climate and favorable soil of cultivation (Pinnow et al., 2013; Camponogara et al., 2016). Among the management technologies, nitrogen fertilization is the most important for increasing grain yield in cereals (Flores et al., 2012; Arenhardt et al., 2015). Nitrogen is considered essential to plants; it is present in the composition of the most important biomolecules such as adenosine triphosphate (ATP), nicotinamide adenine dinucleotide (NADH), Nicotinamide adenine dinucleotide phosphate (reduced form) (NADPH), chlorophyll, proteins and several enzymes (Bredemeier and Mundstock, 2000). In wheat, the nutrient is responsible for the formation of biological molecules and determinant of productivity and grain quality (Fageria et al., 2006; Silva et al., 2015). On the other hand, nitrogen is the element of greater complexity of action on the environmental conditions, resulting in years of high or low temperature and rainfall, significant losses by leaching and/or volatilization, therefore, compromising nutrient use efficiency, reducing productivity, increasing costs and causing environmental pollution (Benin et al., 2012). Thus, there is a need to optimize food production from technologies that ensure productivity with reduced costs and sustainability in agricultural ecosystems (Sala et al., 2005; Viola et al., 2013). In this context, several authors have reported the possibility of using nitrogen economically adjusted to the condition of the agricultural year using fractionation to obtain greater efficiency of grain yield (Arenhardt et al., 2015; Espindula et al., 2014; Mantai et al., 2016).

Nitrogen dose used for cereals gives the expected desired productivity, considering the percentage of soil organic matter and C/N ratio of residual coverage. In soil, nitrogen in the form of ammonium (NH_4^+) or ammonia (NH_3) is rapidly oxidized to nitrite, which in turn is rapidly oxidized to nitrate (Carvalho and Zabot, 2012). Wheat absorbs and metabolizes inorganic nitrogen present in the soil, especially in the form of NO_3^- and NH_4 (Chagas, 2007). Weather conditions significantly alter the plant remains of the preceding crop and the expected productivity. This indicates the need for more efficient management systems to ensure productivity and reduce costs based on the conditions of the crop year. Thus, nitrogen administered in single or double doses under different conditions of crop year, high succession systems and reduced release of N-residual can provide good input to wheat production in Brazil.

The objective of this work is to study the highest amount of nitrogen used for the production of wheat using single dose or fractionation under favorable and unfavorable cultivation year in high succession systems and reduced release N-residual.

MATERIALS AND METHODS

The field experiments were conducted in 2012, 2013 and 2014, in the municipality of Augusto Pestana (28° 26' 30" South and 54° 00' 58" West), Rio Grande do Sul, Brazil. The soil of the experimental area is classified as typical dystrophic red latosol and the climate is classified as Cfa, according to Köppen classification. It has hot summer and without dry season. Soil analysis was carried out ten days before the sowing date and subsequently during the middle of the years it was identified with the following chemical characteristics: (i) Maize/wheat system (pH = 6.5, P = 23.6 mg dm^{-3}, K = 295 mg dm^{-3}, MO = 2.9%, Al = 0 cmolc dm^{-3}, Ca= 6.8 cmolc dm^{-3}, and Mg = 3.1 cmolc dm^{-3}), and (ii) soybean/wheat system (pH = 6.1, P = 49.1 mg dm^{-3}, K = 424 mg dm^{-3}, OM = 3.0%, Al = 0 cmolc dm^{-3}, Ca = 6.3 cmolc dm^{-3} and Mg = 2.5 cmolc dm^{-3}). Sowing was carried out according to the wheat technical indications, mechanically. The experimental units have 5 rows of 5 m long with 0.20 m space, totaling 5 m^2. 45 and 30 kg ha^{-1} of P_2O_5 and K_2O was applied during sowing based on the P and K levels in the soil, in expectation of grain yield of 3 t ha^{-1} and nitrogen in the form of urea. The seeds were submitted for a germination and vigor test in the laboratory in order to provide the desired density of 300 viable seeds per square meters. During the vegetation period, plants were protected against diseases by using FOLICUR® EC fungicide at the dose of 0.75 L ha^{-1}. In addition, the weeds were controlled with an herbicide named ALLY®, known to have reduced stature, early cycle, resistance to lodging, commercial type "bread" and high yield potential. The cultivar is the standard biotype commonly desired by wheat farmers in southern Brazil.

In each cultivation system with high and low N-residual release (soybean/wheat and maize/wheat systems), the experimental design used was a randomized block in a 4 × 3 factorial scheme with four replications consisting of N-fertilizer rates (0, 30, 60 and 120 kg ha^{-1}), forms of supply [one rate (100%), V_3 phenological stage (third expanded leaf); fractionated (70 and 30%) V_3 and V_6 phenological stages (third and sixth expanded leaf); and fractioned (70 and 30%) V_3 and E phenological stages (third expanded leaf and early grain filling)], respectively, totaling 96 experimental units. It is noteworthy that in all the cultivation years, the application of N-fertilizer in V_3, V_6 and E stages, there were 30, 60 and 90 days of emergence of wheat, respectively.

Harvesting was done to estimate grain yield (PG, kg ha^{-1}). It was done manually by cutting the three central rows of each parcel stage near the harvest point (125 days), with grain moisture of about 15%. After harvesting, the beans were threshed with stationary combine harvester and sent to the laboratory for correction of grain moisture to 13%, after weighing and estimating grain yield (PG, kg ha^{-1}).

After checking the assumptions of normality and homogeneity using Bartlett test (STELL et al., 1997), analysis of variance for detection of the main and interaction effects was carried out. Based on this information, we proceeded to the mean comparison test by Scott & Knott's linear (PG = a ± bx) and quadratic (PG = a ± bx ± cx^2) equations. In conditions where there was a significant quadratic effect, the estimate of the maximum technical efficiency of nitrogen was obtained (MET = - [b/2c]) for the maximum grain yield in the different years and succession systems. Grain yield estimation was also obtained through technical recommendation of N-fertilizer in expectation of 3 t ha^{-1} grain, under the succession culture and MO content of soil. In addition, for combined analysis of the time (days) and N fertilizer dose, response surface analysis regression was performed ($Z_i = \beta_0 + \beta_1 X_j + \beta_2 Y_j + \beta_3 X^2_j + \beta_4 Y^2_j + ... + \beta_n X_j Y_j + \epsilon_j$), where, Z_i = dependent variable (grain yield); β_n = Estimates of regression coefficients; X and Y mean the encoded values of factors [conditions for supplying nitrogen (V_3 = 30 days; V_3/V_6 = 60 days; V_3/E = 90 days) and doses (0, 30, 60, 120 kg of N ha^{-1}), respectively]; β_1X_j and β_2Y_j = are responsible for the main effect (interacted factors); β_3X_{2j} and β_4Y_{2j} are responsible for the effects of curvature; $\beta_nX_jY_j$ is responsible for the effects of interactions; ϵ_j is error. For their determination, we used the computer program Genes.

RESULTS AND DISCUSSION

In Figure 1, the maximum temperatures observed in 2012, at the beginning of the wheat development were higher (± 28 °C) compared to 2013 and 2014. This condition favors faster elongation and reduces the incentive to produce new tillers, component directly linked to grain yield. Also in 2012, it was observed high temperatures without rain before and after nitrogen fertilization on stage V_3, a condition that favors loss per volatilization of nutrient. Although the total rainfall was lower compared to historical average (Table 1), weather information together with the reasonable productivity obtained characterizes 2012 as year of intermediate (AI) cultivation. In the agricultural year 2013, the maximum temperature observed at the time of N fertilizer application in the V_3 stage was around 15 °C and favorable conditions of soil moisture by rainfall that occurred in the days prior to fertilization (Figure 1). In Table 1, the total rainfall was similar to the historical average, indicating adequate distribution of rainfall throughout the cycle (Figure 1). These conditions were decisive in the highest average grain yield obtained, characterizing 2013 as a favorable year (FY). In 2014 (Figure 1), the nitrogen supplied indicated maximum temperature of around 23 °C. In addition, nitrogen application was followed by significant rainfall (± 30 mm), a condition also observed near the grain crop. These facts justify the low grain yield obtained in the year (Table 1), through nutrient loss by leaching or damage caused by excessive rainfall at maturity (Figure 1), characterizing 2014 as unfavorable year (AD).

Of all the segments of the economy, agriculture is the one with greater reliance on climate variables, generating output fluctuations over the years (Chies; Yokoo, 2012). Rainfall stands as one of the main elements responsible for these variations (Martins et al., 2010). The prior knowledge of the precipitation conditions may indicate ways of management to ensure the success of the agricultural activity (Arf et al., 2015). The availability of nitrogen in soil and fertilizer efficiency is also influenced by the C/N ratio of residue cover, soil type and rainfall, which vary according to year and location (Arenhardt et al., 2015). Temperature, light and solar radiation are also elements that influence productivity (Souza et al., 2013). The temperature acts as a biological processes catalyst, which is why the plants require a minimum and maximum temperature for normal physiological activities (Tonin et al., 2014). In wheat, favorable weather is described as that of milder temperatures, having radiation that favours tillering and grain filling; without excessive rain; and facilitating adequate supply of moisture stored in the soil (Guarienti et al., 2004; Valério et al., 2009).

In Table 2, in each year of cultivation, there was an interaction between dose fractionation and nitrogen regardless of the succession system. In 2012 (IY), for soybean/wheat and corn/wheat and in 2014 (UY) for soybean/wheat, nitrogen fractionation indicated no change on grain yield. The differences promoted by fractionation, regardless of the succession system were obtained only in 2013 (FY). On the average comparison between the years, 2013 had the highest grain yield, followed by 2012 with regular productivity and 2014 with lower productivity. These results qualify the classification established between favorable (2013), intermediate (2012) and unfavorable (2014) years of wheat cultivation (Table 1).

The improvement of the chemical, physical and biological quality of the soil, especially in no-till system is associated with the previous crop, directly interfering with grain yield (Melero et al., 2013). The wide variation of grain yield is associated with variability of crop conditions, and the proper management of critical nitrogen on wheat productivity increased (Storck et al., 2014). Nitrogen is one of the most required nutrients and, in most cases, is not offered at the optimal dose and time to ensure productivity (Camponogara et al., 2016). Fractionation of nitrogen in wheat has been suggested as an alternative to increase efficiency in the assimilation of nutrients, especially when soil moisture conditions are not appropriate in the nutrient application time (Sangoi et al., 2007). To elucidate these issues, Table 3 shows the nitrogen utilized in single and fractionated conditions under favorable, intermediate and unfavorable conditions for wheat cultivation in succession soybean/wheat and corn/wheat.

Table 3 shows the developmental stage of the wheat crop, regardless of N-fertilizer rates. The year 2012 (IY) in the succession systems (soybean/wheat, corn/wheat) indicated no significant slope of the equation, a condition which reports the absence of differences between the mean grain yields. In 2013 (FY) in both cropping systems, the angular coefficient was negative and significant, a condition which shows reduction in grain yield with the use of fractionation. Therefore, from the V3 stage, reduced productivity occurs at 3.87 kg ha^{-1} in day system in soybean/wheat and 6.39 kg ha^{-1} system in maize/wheat. In 2014 (UY) in the soybean/wheat system, the angular coefficient of the equation was not significant, corroborating similar medium in different conditions of supply of fertilizer.

On the other hand, in the slow release system of N-waste, there was a significant reduction in grain yield (3.26 kg ha^{-1}) per day of fractionation. The results obtained in different conditions of agricultural year indicate disadvantages in the use of fractionation.

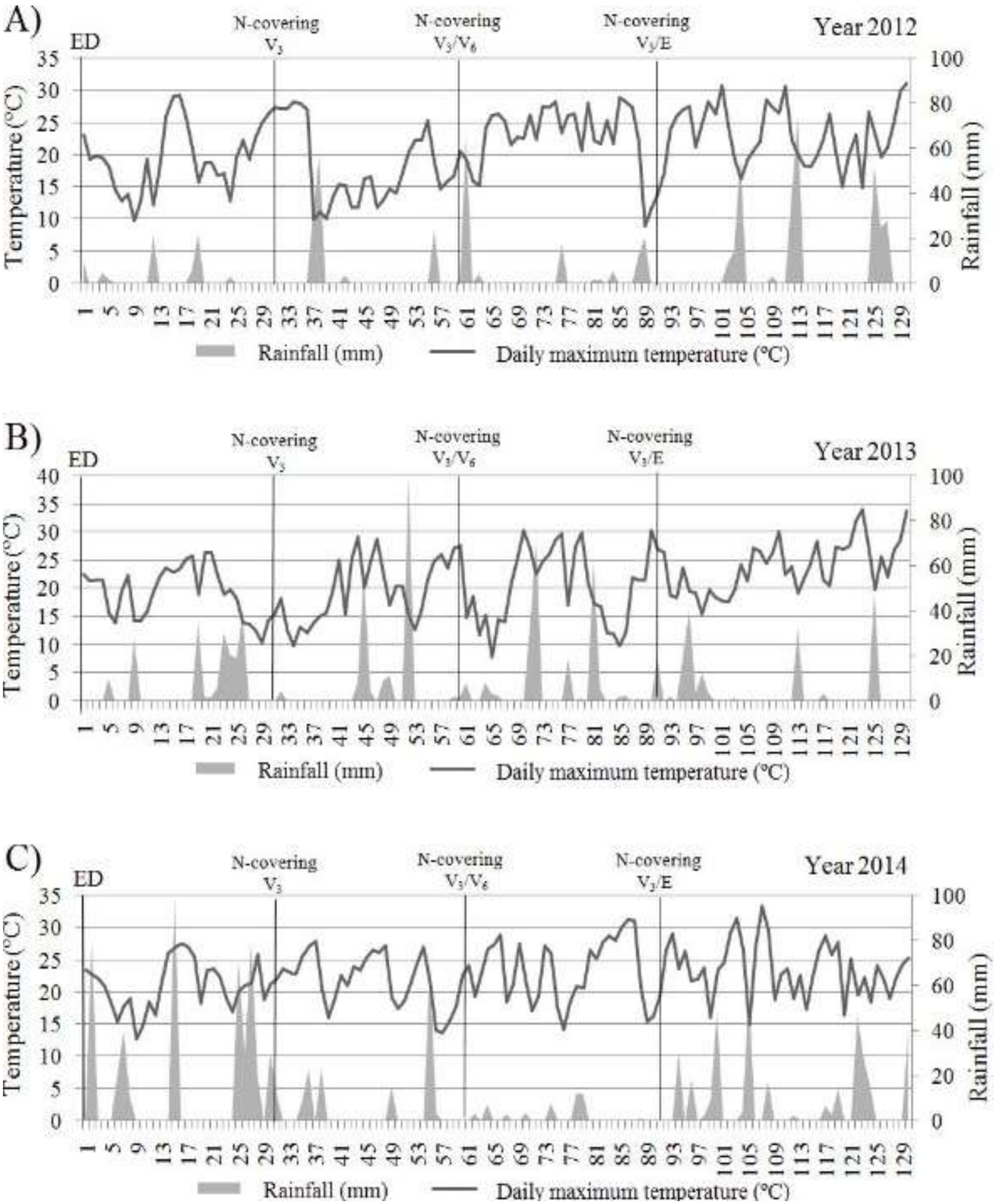

Figure 1. Rainfall and daily maximum temperature in the wheat crop cycle with the days of nitrogen application. ED = emergency date: 2012 (27 June); 2013 (17 June); 2014 (25 June). DAE = days after emergency. V3 = full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth expanded leaf; and V_3/E = fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling.

Table 1. Temperature and rainfall in the month of cultivation and average productivity.

Year	Month	Temperature (°C)			Rainfall (mm)		$GY_{\bar{x}}$ (kg ha^{-1})	Class
		Minimum	Maximum	Average	Average 25 years*	Occurred		
2012	May	11.1	24.5	17.8	149.7	20.3	2441	IY
	June	9.3	19.7	14.5	162.5	59.4		
	July	7.4	17.5	12.4	135.1	176.6		
	August	12.9	23.4	18.1	138.2	61.4		
	September	12	23	17.5	167.4	194.6		
	October	15	25.5	20.2	156.5	286.6		
	Total	-	-	-	909.4	798.9		
2013	May	10.5	22.7	16.6	149.7	100.5	3357	FY
	June	7.9	18.4	13.15	162.5	191		
	July	8.3	19.2	13.75	135.1	200.8		
	August	9.3	20.4	14.85	138.2	223.8		
	September	9.5	23.7	16.6	167.4	46.5		
	October	12.2	25.1	18.65	156.5	211.3		
	Total	-	-	-	909.4	973.9		
2014	May	10.8	23.6	17.2	149.7	412	1414	UY
	June	8.6	19	13.8	162.5	412		
	July	9.7	21.82	15.76	135.1	144		
	August	8.8	23.66	16.23	138.2	77.8		
	September	13.33	23.58	18.46	167.4	274.8		
	October	16.02	27.49	21.76	156.5	230.8		
	Total	-	-	-	909.4	1551.4		

*= Average rainfall obtained in the months from May to October 1989-2014; IY = intermediate year; FY = favorable year; UY = unfavorable year; GY_X = average grain yield.

Although the year 2012 (IY) does not show reduced productivity by fractionation, the averages were similar to N-fertilizer application in a unique way, which would reduce costs, time and manpower with only a single application. Espindula et al. (2010) point out that years of favorable and unfavorable climate change the nitrogen availability and use efficiency by the plant reflected in productivity. Ma et al. (2010) described the amount and timing of fertilization should be considered carefully, because high doses and late or early applications can be inefficient, especially in conditions of low soil moisture or high rainfall after fertilization. In this context, the nitrogen fertilization should be highlighted, not only due to the high cost that it represents, but also due to the efficient use with guaranteed sustainability (Costa et al., 2013). Studies by Mundstock (1999) report that the supply of nitrogen in fractionated condition seeks to provide more efficient assimilation of the nutrients by wheat, a condition that was not observed from the results presented in Table 3.

Table 4 shows the models that seek to validate the behavior of wheat grain yield expression for the maximum technical efficiency of nitrogen use and expectation of grain yield of 3 t ha^{-1}, regardless of single supply condition and nitrogen split in years and succession systems. The expected grain yield estimate of 3 t ha^{-1} was obtained due to the content of soil organic matter and the succession system (soybean/wheat = 60 kg N ha^{-1}, corn/wheat = 90 kg N ha^{-1}) according to technical indication for culture. In 2012 (IY), in the soybean/wheat system, the quadratic equation was significant, describing optimal dose of nitrogen with 110 kg ha^{-1} and simulated yield in 2869 kg ha^{-1}. On the other hand, considering the expected dose of 3 t ha^{-1}, the use of 60 kg ha^{-1} of nutrient led to large reduction of cost of fertilization while maintaining optimal dose. The quadratic behavior was also obtained in 2014 (UY) and provided a grain yield of 1704 kg ha^{-1} with 89 kg ha^{-1} N-fertilizer. It is noteworthy that the dose used for the expectation of 3 t ha^{-1} (60 kg ha^{-1}) indicated grain yield of around 1600 kg ha^{-1}.

These facts reinforce that nitrogen can be substantially reduced or increased based on the condition of the year of cultivation and the use of optimal dose may not necessarily express maximum grain yield with economic efficiency. In 2013 (FY), linearity was obtained in the

Table 2. Summary of the analysis of variance of nitrogen dose fractionation and comparison of average year wheat cultivation in succession systems.

Change source	DF	Mean square	
		Grain yield (kg ha^{-1})	
		Soybean/wheat system	Corn/wheat system
		2012 (IY)	
Block	3	17877	51477
Fractionation (F)	2	6878^{ns}	65216^{ns}
Dose (D)	3	3034309*	8554725*
F x D	6	116598*	80829*
Error	33	33347	22162
Total	47		
General average		2613^{b}	2270^{b}
CV (%)		7.89	7.52
		2013 (FY)	
Block	3	183194	8670
Fractionation (F)	2	238388*	609325*
Dose (D)	3	14866902*	38371527*
F x D	6	71559*	297203*
Error	33	35417	23303
Total	47		
General average		3691^{a}	3023^{a}
CV (%)		5.79	5.91
		2014 (UY)	
Block	3	75262	9756
Fractionation (F)	2	41615^{ns}	164537*
Dose (D)	3	817841*	1602882*
F x D	6	49807*	37256*
Error	33	15033	15129
Total	47		
General average		1561^{c}	1268^{c}
CV (%)		8.57	11.0

* = Significant at 5% error probability; ns = not significant at 5% probability of error; DF = degrees of freedom; CV = coefficient of variation; IY = Intermediate Year; FY = favorable year; UY = unfavorable year; Means followed by the same letter in the column do not differ by the Scott Knott model.

behavior of grain yield in high and reduced release of N-waste systems, a condition that reports the benefits of favorable year in using nitrogen to prepare grains. It is noteworthy that 60 kg ha^{-1} dose expressed nitrogen values above the expected 3 t ha^{-1}. In the slow release system of N-residual (Table 4), the nitrogen used for the grain was linear, regardless of intermediate year, favorable and unfavorable conditions for wheat cultivation. The results corroborate the agricultural year classification (Table 1), because at the intermediate condition there was increased grain yield by 15.9 kg ha^{-1} per kilogram of nitrogen applied. In favorable condition (Costa et al., 2013), each kilogram of nitrogen applied per hectare gave 19.4 kg ha^{-1} of grain yield. On the other hand, the unfavorable condition in 2014 exhibited lower nitrogen used for the preparation of grains with 6.7 kg ha^{-1} productivity per kilogram of nitrogen. In this condition, the nitrogen dose expectation of 3 t ha^{-1} (90 kg N ha^{-1}), promoted an estimated yield of 1366 kg ha^{-1}. Therefore, in an unfavorable year, investments in fertilizer should be reduced, noting the cost/benefit ratios.

Espindula et al. (2010) obtained the highest grain yield with doses ranging from 70 to 120 kg ha^{-1} of nitrogen. Heinemann et al. (2006) point out that the wheat under irrigation has a positive response up to 156 kg ha^{-1} with estimated productivity of 6472 kg ha^{-1}. Vianal (2010) claims that nitrogen is the nutrient which interferes mostly with wheat composition and is mostly demanded during its development.

On the other hand, the nitrogen supplied to plants

Table 3. Regression equation to estimate grain yield and average productivity in stages (days) of the supply of nitrogen in cropping systems.

Year	Phenological stage (application day N)	GY (kg ha^{-1})	Equation GY = a ± bx	R^2 (%)	P (b_{ix})
		Soybean/wheat system			
2012 (IY)	V_3 (30)	2294[a]	2272+0.68x	98	ns
	V_3/V_6 (30/60)	2311[a]			
	V_3/E (30/90)	2335[a]			
2013 (FY)	V_3 (30)	3346[a]	3484-3.87x	90	*
	V_3/V_6 (30/60)	3295[a]			
	V_3/E (30/90)	3113[b]			
2014 (UY)	V_3 (30)	1488[a]	1504-1.21x	50	ns
	V_3/V_6 (30/60)	1390[a]			
	V_3/E (30/90)	1415[a]			
		Corn/wheat system			
2012 (IY)	V_3 (30)	1908[a]	1858+2.03x	91	ns
	V_3/V_6 (30/60)	2002[a]			
	V_3/E (30/90)	2030[a]			
2013 (FY)	V_3 (30)	2754[a]	2967-6.39x	96	*
	V_3/V_6 (30/60)	2626[a]			
	V_3/E (30/90)	2371[b]			
2014 (UY)	V_3 (30)	1200[a]	1313-3.26x	93	*
	V_3/V_6 (30/60)	1149[a]			
	V_3/E (30/90)	1005[b]			

V_3 = single condition (100%) of the nitrogen dose in the third expanded leaf (30 days); V_3/V6 = fractional condition (70% / 30%) of the nitrogen dose in the third and sixth expanded sheet (30 and 60 days); V_3/E = fractional condition (70% / 30%) of the amount of nitrogen in the third expanded leaf and early grain filling (30 and 90 days); R^2 = coefficient of determination; IY = intermediate year; FY = favorable year; UY = unfavorable year; GY = grain productivity (kg ha^{-1}); P (b_ix) = slope significance of probability; * = Significant at 5% probability of error for the test; ns = not significant; means followed by the same letter in the column do not differ by the Scott Knott model.

depends, among other factors, on the amount of soil nutrients, the composition of plant residues, the expected desired productivity and humidity, aeration and temperature interaction in cropping systems (Rocha et al., 2008; Romitti et al., 2016). Therefore, the biochemical composition of crop residues used for determining nitrogen mineralization or immobilization may affect the dosages and times of N-fertilizer of the rate of soil nitrogen release and decomposing tissues (Mantai et al., 2016).

The analysis of the grain yield involving dose of interrelations with the N-fertilizer fractionation can be better understood if the mathematical function that simultaneously adds these sources of variation is known. One way to express this function can be obtained by regression analysis using response surface. Therefore, in Table 5, the different models tested are shown as a way of simulating grain yield in different culture conditions. Among the equations obtained, one with the highest coefficient of determination is more efficient to explain the simultaneous behavior between dose and form of nitrogen supply. This condition was obtained using the following mathematical structure:

$$Z = b_0 \pm b_1X + b_2Y - b_3Y^2$$

Table 6 shows the values of simulated grain yield by response surface regression model, the combined dose analysis and condition of nitrogen supply based on agricultural year and succession system. The results obtained in soybean/wheat system and maize/wheat showed increased grain yield with the increase of fertilizer nitrogen mainly in intermediate year (2012) and favorable (2013) cultivation. This increase was significant at succession system with reduced C/N ratio (soybean/wheat), which promotes increased release of this residual N-cultivation system. In all conditions analyzed in the year and nitrogen rate, the use of fractionation showed no increase in the simulated values grain yield.

The results give support when stating that although it occurs favorable years, intermediate and unfavorable to wheat cultivation, the use of single dose of nitrogen is more advantageous. In addition, the optimum dose of the

Table 4. Regression equation of grain yield and average wheat productivity in nitrogen and define the optimal dose with simulation of grain yield.

Year	Dose (N)	GY (kg ha^{-1})	Equation GY= a ± bx ± cx^2	R^2 (%)	P (b_{ix})	$N_{(MET)}$ (kg ha^{-1})	$GY_{(MET)}$ (kg ha^{-1})	$N_{(PG= 3\ t\ ha^{-1})}$ (kg ha^{-1})	GY_E (kg ha^{-1})
Soybean/wheat system									
2012 (IY)	0	1607[c]	1659+22x-0.10x^2	95	*	110	2869	60	2619
	30	2366[b]							
	60	2492[b]							
	120	2787[a]							
2013 (FY)	0	1930[d]	2132+21.3x	96	*	-	-	60	3410
	30	2871[c]							
	60	3665[b]							
	120	4539[a]							
2014 (UY)	0	1069[c]	1065+14.3x-0.08x^2	99	*	89	1704	60	1635
	30	1412[b]							
	60	1638[a]							
	120	1605[a]							
Corn/wheat system									
2012 (IY)	0	919[d]	1141+15.9x	94	*	-	-	90	2572
	30	1808[c]							
	60	2264[b]							
	120	2929[a]							
2013 (FY)	0	1263[d]	1564+19.4x	92	*	-	-	90	3310
	30	2467[c]							
	60	2851[b]							
	120	3753[a]							
2014 (UY)	0	647[d]	763+6.7x	84	*	-	-	90	1366
	30	1035[c]							
	60	1298[b]							
	120	1491[a]							

GY = Grain yield (kg ha^{-1}); N = nitrogen; N (MET) = Maximum technical efficiency of nitrogen use; PG (MET) = Grain yield the maximum technical efficiency of nitrogen use; N (PG = 3 t ha^{-1}) = nitrogen dose for expectation of 3 t ha^{-1} of grain yield; GY_E = estimated grain yield; MET = Maximum technical efficiency; IY = Intermediate Year; FY = Favorable year; UF = Unfavorable year; R^2 = coefficient of determination; P (b_ix) = Probability of slope of significance; * = Significant at 5% probability of error for the test; ns = not significant; Means followed by the same letter in the column do not differ by the Scott Knott model.

N-fertilizer should not always be indicated, especially in unfavorable conditions for cultivation, since the utilization efficiency of the nutrient to the grains preparation is drastically reduced. Although the fertilizer around the phenological stage V_3 is shown to be more appropriate, it is essential that the soil moisture conditions are suitable for enabling greater absorption of nutrients by the plant. Therefore, suggesting that the supply of nitrogen in the growth stage V_4 and V_5 can also be considered, provided that there are suitable conditions for nitrogen supply stage V_3. Even the wheat technical specifications mention the possibility of fertilization with N-fertilizer in a range that goes from 30 to 60 days after emergence of wheat seedlings.

Response surface analysis is a method that comprises a set of mathematical and statistical procedures used in the model to develop, improve and optimize processes (Zhang et al., 2009; Santos et al., 2014). With surface analysis response, the best conditions of hydrothermal pre-treatment in sugarcane were determined (Ferreira et al., 2015). Using this methodology, greater efficiency of live weight ratio of broiler chickens against the feed intake and its feed conversion was achieved. Therefore, an optimization technique that also allows simulations may indicate the behavior of important processes, and the efficient use of natural and biological resources in agriculture.

Conclusion

In favorable, intermediate and unfavorable years of wheat

Table 5. Response surface models on the combined use of doses and conditions of supply of nitrogen to wheat grain yield in cropping systems.

Soybean/wheat system			Corn/wheat system		
Model		**R^2**	**Model**		**R^2**
		2012 (IY)			
Z=2271+0.68749X		12	Z=1858+ 20302X		13
Z=1851+ 8.78936Y		66	Z =1141+ 15.97801Y		88
Z=1810+ 0.68749X + 8.78936Y		66	Z=1019+ 2.0302X+ 15.97801Y		89
$Z=1822+0.19583X + 0.00409X^2+ 8.78936Y$		66	$Z=908+6.45104X-0.03685X^2+15.97801Y$		89
$Z=1618+ 0.68749X+ 22.04781Y -0.10668Y^2$		79	$Z=825+2.0302X+29.36933Y-0.10775Y^2$		94
$Z=1630+0.195X+0.004X^2+22.047Y-0.106Y^2$		78	$Z=714+ 6.451X-0.036X^2+29.369Y-0.107Y^2$		93
Z=1875-0.39751X+7.54936Y+0.02066XY		66	Z =1180-0.65X+12.91492Y+0.05105XY		89
X minimum = 30	Y maximum = 120		X minimum = 30	Y maximum= 120	
X maximum = 90	Z minimum = 1332		X maximum = 90	Z minimum= 788	
Y minimum = 0	Z maximum = 3023		Y minimum = 0	Zbmaximum=3364	
		2013 (FY)			
Z=3483-3.87188X		9	Z=2966-6.38855X		3
Z=2131+21.31817Y		90	Z=1564+19.4169Y		84
Z=2364-3.87188X+ 21.31817Y		91	Z=1947-6.38855X+19.4169Y		87
$Z=2147+ 4.79062X-0.07219X^2+ 21.31817Y$		91	$Z=1735+2.09895X-0.07073X^2+19.4169Y$		87
$Z=2155-3.87188X+ 35.74258Y-0.11606Y^2$		95	$Z=1716-6.38855X+35.34571Y-0.12817Y^2$		92
$Z=1938+ 4.790X-0.072X^2+35.742-0.116Y^2$		94	$Z=1504+2.098X-0.070X^2+35.345Y-0.128Y^2$		91
Z=2418-4.78001X+20.28031Y+0.01729XY		91	Z=1743-2.99834X+23.29142Y-0.06458XY		87
X minimum = 30	Y maximum = 120		X minimum = 30	Y maximum = 120	
X maximum = 90	Z minimum = 1678		X maximum = 90	Z minimum =1109	
Y minimum = 0	Z maximum = 5024		Y minimum = 0	Z maximum =4081	
		2014 (UY)			
Z=1503-1.21146X		18	Z=1313-3.26146X		5
Z=1212+ 4.15492Y		45	Z=763+6.74873Y		73
Z=1285-1.21146X+4.15492Y		47	Z=959-3.26146X+6.74873Y		78
$Z=1492-9.47396X+0.06885X^2+4.15492Y$		48	$Z=805+2.8927X-0.05129X^2+6.74873Y$		78
$Z=1138-1.21146X+14.33761Y-0.08193Y^2$		70	$Z=843-3.26146X+14.73419Y-0.06426Y^2$		87
$Z=1344-9.473X+0.068X^2+14.337Y-0.081Y^2$		69	$Z=689+2.89X-0.051X^2+14.734Y-0.064Y^2$		86
Z=1335-2.04667X+3.20039Y+0.0159XY		47	Z=1028-4.4175X+5.42753Y+0.02201XY		78
X minimum = 30	Y maximum = 120		X minimum = 30	Y maximum = 120	
X maximum = 90	Z minimum = 891		X maximum = 90	Z minimum =411	
Y minimum = 0	Z maximum = 2048		Y minimum = 0	Z maximum =1773	

Z = Grain yield (kg ha^{-1}); X = nitrogen supply condition [V_3 = single condition (100%) of the nitrogen rate in the third expanded leaf (30 days); V_3/V_6 = fractional condition (70% / 30%) of the nitrogen rate in the third and sixth expanded sheet (60 days); V_3/E = fractional condition (70% / 30%) of the amount of nitrogen in the third expanded leaf and early grain filling (90 days)]; Y = nitrogen doses (0, 30, 60, 120 kg ha^{-1}); IY = Intermediate year; FY = favorable year; UY = unfavorable year; R^2 = coefficient of determination.

cultivation the supply of nitrogen in single dose is more effective than the development of the grain using fractionation, regardless of the succession system.

The nitrogen use efficiency can be substantially reduced or increased in wheat based on the year of cultivation, and the use of optimal dose of the nutrient may not necessarily express maximum grain yield with economic efficiency.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Table 6. Value estimated by the model of response surface regression in predictability of grain yield in cropping systems.

Year	Dose N ($kg\ ha^{-1}$)	Phenological stage (days)	$Z = b_0 \pm b_1X + b_2Y - B_3Y^2$ ($kg\ ha^{-1}$) Soybean/Wheat	Corn/Wheat
2012	0	V_3 (30)	1639	886
		V_3/V_6 (60)	1659	947
		V_3/E (90)	1680	1008
	30	V_3 (30)	2204	1670
		V_3/V_6 (60)	2225	1731
		V_3/E (90)	2243	1792
(IY)	60	V_3 (30)	2577	2260
		V_3/V_6 (60)	2598	2321
		V_3/E (90)	2619	2382
	120	V_3 (30)	2748	2859
		V_3/V_6 (60)	2769	2920
		V_3/E (90)	2789	2980
2013	0	V_3 (30)	2039	1524
		V_3/V_6 (60)	1923	1333
		V_3/E (90)	1807	1141
	30	V_3 (30)	3001	2469
		V_3/V_6 (60)	2891	2278
		V_3/E (90)	2774	2086
(FY)	60	V_3 (30)	3766	3184
		V_3/V_6 (60)	3649	2992
		V_3/E (90)	3533	2800
	120	V_3 (30)	4657	3920
		V_3/V_6 (60)	4541	3729
		V_3/E (90)	4424	3537
2014	0	V_3 (30)	1102	745
		V_3/V_6 (60)	1065	647
		V_3/E (90)	1029	549
	30	V_3 (30)	1458	1129
		V_3/V_6 (60)	1422	1032
		V_3/E (90)	1385	934
(UY)	60	V_3 (30)	1667	1398
		V_3/V_6 (60)	1631	1300
		V_3/E (90)	1594	1202
	120	V_3 (30)	1642	1588
		V_3/V_6 (60)	1607	1490
		V_3/E (90)	1570	1392

N = nitrogen; Z = grain yield ($kg\ ha^{-1}$); X = nitrogen supply condition [V_3 = single condition (100%) of the nitrogen rate in the third expanded leaf (30 days); V_3/V_6 = fractional condition (70% / 30%) of the nitrogen rate in the third and sixth expanded sheet (60 days); V_3/E = fractional condition (70% / 30%) of the amount of nitrogen in the third expanded leaf and early grain filling (90 days)]; Y = nitrogen doses (0, 30, 60, 120 $kg\ ha^{-1}$); IY = Intermediate year; FY = favorable year; UY = unfavorable year.

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Full Length Research Paper

Effect of Global-GAP policy on smallholder French beans farmers' climate change adaptation strategies in Kenya

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This study analyzed the role of Global-GAP policy, on smallholder French beans farmers' climate change adaptation strategies in, fruit and vegetables farming. It considered: (1) the prevailing adaptation strategies used by the farmers; (2) regional differences in the farmers' adaptation strategies; and (3) how Global-GAP policy influence the farmers' decisions on the use of adaptation strategies. A total of 616 French beans growing households were randomly selected from Central and Eastern regions of Kenya and data collected through semi-structured questionnaire. Principal Component Analysis (PCA) and a logistic regression model were used to analyze the data. PCA results showed that, the French beans farmers' prevailing adaptation strategies were soil conservation, water harvesting, off-farm employment, leasing out of land, changing crop variety, irrigation and livestock rearing. The common study area-wide adaptation strategies to climate change were found to be, soil conservation and leasing out land. The empirical results of the logistical model showed that, Global-GAP policy compliance significantly and positively increased the probability of the farmers to undertake changing crop variety, water harvesting, finding off-farm jobs and soil conservation as adaptation strategies to climate change. The policy implication of this study is that, government and service providers should mainstream such factors as Global-GAP compliance and regional considerations which enhance the probability of adopting adaptation strategies to climate change related projects and programmes in the smallholder fruits and vegetables farming sector.

Key words: Global-GAP policy, climate change adaptation, prevailing adaptation strategies, principal component analysis, logistical regression model, smallholder farming.

INTRODUCTION

With the increasing climate change risks facing small-holder fresh fruit and vegetables farming in Sub Saharan Africa (SSA), the need for farmers supplying markets in the developed countries to adopt suitable adaptation

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strategies is becoming more pronounced (FAO, 2013; IPCC, 2001). Climate change is progressively having negative effect on crop yields in SSA (Niang et al., 2014; Kabubo-Mariara and Karanja, 2007). This, coupled with growing environmental consciousness among consumers in European Union (EU) forming the main market for fresh fruit and vegetables, is already presenting real and potential livelihood consequences to smallholder farmers (Macgregor, 2010; Wangler, 2006).

About 40% of all fresh fruit and vegetables exports into the EU are produced in SSA and this supports the livelihoods of about 1 million people (Legge et al., 2006; World Bank, 2010a). In East Africa, it supports the livelihood of at least a quarter of million people with the fastest growth being registered in chillies, green peppers and French beans (Edward-Jones et al., 2009). Among the fresh vegetables, Kenya is currently the leading exporter of French beans to the EU and is mostly grown by smallholders (Minot and Ngigi, 2004; Mutuku et al., 2004). French beans accounts about 60% of all vegetables and 21% of horticultural exports in Kenya (Okello et al., 2007). About 90% of French beans are produced in smallholdings, ranging between 0.15 to 2 hectares (Odero et al., 2012).

Despite the growing export market demand for French beans, the area under production, volume and value have been declining due to climate related effects. Between 2008 and 2010, the area, volume and value decreased by 37, 39 and 45%, respectively due to prolonged drought experienced in Kenya in the year 2008 to 2009 (HCDA, 2010). This provide an indication that, climate related risks coupled with poor adaptation strategies, might be compounding the livelihood challenges of smallholder French beans farmers in the traditional production areas (Legesse and Drake, 2005; O'Brien et al., 2000). Adoption of suitable adaptation strategies is thus a pre-requisite to supporting majority of smallholder farmers in reducing effects of climate change and changing socioeconomic conditions like, changes in local and export markets (Bryant et al., 2000; Boko et al., 2007; Fussel, 2007).

Over the period, most EU countries providing the market for French beans have enforced regulatory mechanisms aimed at addressing climate change's impacts (Appleton, 2007; MacGregor and Vorley, 2006; Rigby and Brown, 2003). These regulatory measures, coupled with commercial risks have led private buyers in EU to enforce their own private voluntary standards (PVS), pertaining to environmental risks (Bingley, 2008; Jaffee et al., 2005).

Among the PVS, Global-GAP policy has notably gained significance in supporting access to required production management skills and climate change adaptation capacity in Kenya's French beans farming (Amekawa, 2009; Edward-Jones et al., 2009; Government of Kenya, 2010a; Kariuki, 2014; Liu, 2009). At the national level, the environmental objective of Global-GAP is seen to be consistent with climate action plans, which aims to support initiatives for helping farmers to adopt appropriate climate change adaptation strategies, towards enhancing food security (Government of Kenya, 2010b).

Evidence suggest that, although smallholder farmers are likely to be seriously affected by climate change, only a minority of them have taken advantage of adaptation strategies (Fosu-Mensah et al., 2012). Identification of trends that advocates local climate change adaptation strategies and influencing factors are therefore considered vital in guiding farmers' adaptation decisions (Belliveau et al., 2006; Bryant et al., 2000; Maddison, 2006). A number of factors, among policies and markets, have been identified to define responses of the farmers to climate change shocks (Blengini and Busto, 2009; Bradshaw et al., 2004; Bryant et al., 2000; Nhemachena and Hassan, 2007).

While much has been done on farm-level adaptation strategies, very little focus has been given to the link between Global-GAP policy and prevailing climate change adaptation strategies of smallholder French beans producers. This underlies the growing concern that, unless this link is established, it will be difficult to support increased compliance among developing-country smallholder producers and may lead to reduced market access (Minae et al., 2006). A clear understanding of the role of Global-GAP policy on the decision by smallholder French beans farmers to use certain climate change adaptation strategies is therefore essential in, supporting policy makers and industry service providers in designing suitable strategies in smallholder fresh fruit and vegetables farming (Mabe et al., 2012). The question therefore remains: what is the prevailing climate change adaptation strategies used by French beans farmers; are there regional differences in climate change adaptation strategies; does Global-GAP compliance influence the decisions on specific adaptation strategies used by farmers?

MATERIALS AND METHODS

The data used in the analysis was collected in Central and Eastern regions of Kenya, which are the leading French beans producing areas in the country. About 90% of the total national French beans output is produced by smallholder farmers in these regions under increasing challenge of climate effects. A higher proportion of French beans farmers in these areas are also complying with Global-GAP policy to enhance their export market access. The integrated farm management practices and technologies promoted under Global-GAP policy in these areas are also assumed to be climate change adaptation related, targeted at reducing vulnerability and improving agricultural production potential (Government of Kenya, 2010b; Amekawa, 2009). The study interviewed a random sample of 616 Global-GAP complying and non-complying farmers using a semi-structured questionnaire.

The number of smallholder French beans farmers interviewed from each region was arrived at using proportionate to size criteria.

Multistage sampling was used to select the counties, sub-counties, wards and the villages from which farmers were selected. Systematic random sampling was used to select farmers to be interviewed in each of the selected region. Only household decision maker/spouse was interviewed. Data collected included information on Global-GAP compliance, weather related risks and adaptation strategies applied by farmers. Factor analysis and logistic regression methods were used to analyze data. Descriptive statistics such as mean and percentages were generated using Statistical Package for Social Scientists (SPSS). Factors affecting adoption of adaptation strategies were analyzed using Limdep software.

Assessment of prevailing climate change adaptation strategies

The study modelled climate change adaptation in smallholder French beans farming on technology adoption theory since adaptation to climate change in agriculture is mostly through, adoption of appropriate technologies (Gbetibouo, 2009). The models were based on farmers' utility and profit maximizing behaviors. The study identified underlying climate change adaptation strategies, applied by the farmers using factor analysis. This was used to reduce large numbers of observed farmers' variables to fewer underlying dimensions, viewed as a more authentic measure of that factor (Helena et al., 2000; Sarbu and Pop, 2005).

To ensure that all the variability in the observed variables was used, the study applied the principal component analysis (PCA) as the data reduction method during the factor analysis (Lwayo and Obi, 2012). In addition, the study used Likert scale to find out the general clustering of variables for explanatory purposes, under the believe that variable correlation is less than 0.6 (Kim and Mueller, 1987). The principal components were ordered in such a way that, the first component accounted for the largest possible amount of variation in the original variables, the second component accounted for the maximum that was not accounted for by the first and was completely uncorrelated with the first principal component (Rao,1964). The computation of the principal component was as follows:

$$PC_n = f\,(a_{ni}X_i \ldots\ldots\ldots\ldots\ldots a_{1k}X_k) \qquad (1)$$

Where PC is the component score, n is the total number of PCs, *a* is the component loading, *X* is the measured value of variable, *i* is the component number and *k* is the total number of variables. If the number (n) of principal components is greater than 1, then each principal component is a continuous variable or quantity related to, the products of the values of the constituent variables and their respective weightings or component loading (a). The relationship is an additive and hence the value of the principal component can be obtained by, addition of the products as shown in the equation:

$$PC_n = f\,(a_{11}X_1 + a_{12}X_2 + \ldots\ldots\ldots\ldots\ldots a_{1k}X_k) \qquad (2)$$

Where PC1 is the first principal component, a_{1k} is the regression coefficient for the kth variable that is the eigenvector of the covariance matrix between the variables, and X_k the kth variable. Since key climate change adaptation strategies of the farmers were derived from actual observed data, assumption was made in the study that, there was no difference in adaptation strategies used in the two study regions. Further assumption was made, climate change adaptation measures was an "aggregate of indicators", then adaptation strategies of French beans smallholder farmers aggregated region-wide reflected factors that speak to the complex latent measures used by farmers to adapt to climate change in the two regions. For this purpose, data for all farmers' responses across the region were combined for each region. The farmers gave their responses on the measures adopted for climate change adaptation on the Likert scale of one to three (where 1 = disagree, 2 = unsure/neutral, and 3 = agree).

The adaptation strategies tested include twelve items. The 12 items include: changing crop variety, building a water harvesting scheme, planting shaded trees, irrigating more, changing from crop to livestock, increasing number of livestock, reducing the number of livestock, migrating to another area, finding off-farm jobs, leasing their land, buying insurance and investing in soil conservation techniques. These were reduced using PCA while still reflecting a large proportion of the information contained in the original dataset. The data was screened to ensure no outliers and the minimum amount of data for factor analysis was satisfied for each group with a sample size of 307 for the eastern region farmers and 309 for central region farmers. All the variables analysed satisfied several well-recognized criteria for factorability of correlation. The Kaiser-Meyer-Olkin measure of sampling adequacy considered was above the threshold of 0.5 and any value below 0.5 was considered miserable according to Everitt and Hothorn (2011). The Bartlett's test of sphericity for the two regions was done at 1% level of significance. The varimax rotation which is a form of orthogonal rotation strategy was used since there was no relationship between the components.

Assessment of the influence of Global-GAP policy on farmers' climate change adaptation strategies decisions

The study assumed that use of identified adaptation strategies was influenced by socio-economic factors among them Global-GAP policy compliance. Other factors deemed to influence adoption of modelled adaptation strategies which were based on literature review and included respondents' socio-economic and institutional factors (Nhemachena and Hassan, 2007). The dependent variable was binary (1 if farmer used identified adaptation strategies, 0 otherwise). The climate change adaptation strategies function for smallholder French beans farmers was specified as:

$$CCS_i = f\,(G_i, FE_i, E_i, GGC_i \ldots\ldots\ldots) \qquad (3)$$

Where: CCA = binary (1 if farmer was using adaptation strategy i, 0 otherwise); G = Gender; FE = Farming experience; E = extension and GGC = Global-GAP Compliance. The estimated model was specified as:

$$CCA = X_i\beta_i + \mu \qquad (4)$$

Where X was a vector of explanatory variables, β was a vector of coefficients and μ was a random variable accounting for unobservable characteristics. Logistic regression model was used to estimate the explanatory variables, influencing the adoption of the identified climate change adaptation strategies by the farmers.

Empirical model for determinants of climate change adaptation

The dependent variable for the logistic regression equation was, whether a farmer adopted the identified climate change adaptation strategies or not. The explanatory variables for the equations were chosen, based on climate change adaptation literature and data availability. The description and hypothesized signs of the modelled variables are presented in Table 1.

Table 1. Variables hypothesized to affect decisions on adaptation strategies by farmers in Central and Eastern regions.

Variable	Description	Value	Expected sign
	Household characteristics		
Gender	Gender farm household head	1 if male, 0 otherwise	+ or -
Household size	Number of family members of a household	Number	+ or -
Farming experience	Years of farming experience for household head	Number	Positive
Wealth	Measured in tropical Livestock Unit index	Number	Positive
Farm size	Acreage of land put under French beans	Hectare	Positive
Soil fertility	Farmer's perception on the fertility level of his/her land	0 = infertile, 1 = fertile, 2 = highly fertile	Positive
	Institutional factors		
Extension	If household has access to extension services	1 if accessed, 0 otherwise	Positive
Distance to market	Distance to the nearest market in km	Number	Negative
Weather information	If household gets information about weather, climate from any source	1 if accessed, 0 otherwise	Positive
Credit	If household has access to credit from any sources	1 if accessed, 0 otherwise	Positive
Land ownership	If land use is owned or rented	1 if owned, 0 otherwise	Positive
Global-GAP compliance	If complying with Global-GAP policy	Probability of complying with Global-GAP policy	Positive
Region	Region where the farmer is operating from	1 if Central, 0 otherwise	Positive
Reduction in rainfall	Perception on reduction in rainfall	1 if reduced, 0 otherwise	Positive
Increase in temperature	Perception on increase in temperature	1 if increased, 0 otherwise	Negative

Source: Survey data, 2013.

RESULTS AND DISCUSSIONS

Prevailing climate change adaptation strategies of farmers

The study results showed that 70% of smallholder French beans farmers interviewed used at least one type of adaptation strategies in response to long term changes in rainfall and temperature. By region, 59% and 79% of farmers interviewed in Central and Eastern regions respectively used at least, one type of adaptation strategies. Factor analysis was undertaken to understand the specific prevailing climate change adaptation strategies, used by smallholder French beans farmers to reduce the effects of changes in rainfall and temperature. A total of three and one items were eliminated respectively in Central and Eastern regions because they did not contribute to a simple factor structure and failed to meet a minimum criterion of having a primary factor loading of 0.5 or above. All the extracted components in both regions had an eigen values of above 1. The suggested KMO values in the analysis in the two regions were all above 0.6 and Bartlett's test of sphericity, were significant at 1%, supporting the factorability of correlation matrix.

Adaptation strategies to changes in rainfall

The study extracted three principal components (PCs) each from responses of farmers in Central and Eastern region on their adaptation strategies, to long term changes in rainfall. The components represented major adaptation strategies used by farmers in the two regions. In Central region, the three extracted PCs contributed about 53% of the variance. Based on the items loadings, the

Table 2. Factor loadings and communality for adaptation strategies to long-term shift in rainfall in Central Region (n = 253).

Items	Soil Conservation	Leasing out land	Water harvesting	Communality
Invested in Soil Conservation techniques	0.74	0.02	-0.04	0.54
Planted shaded trees	0.70	-0.07	-0.01	0.50
Changed crop variety	0.66	0.03	0.47	0.65
Have found off-farm jobs	0.62	0.21	-0.28	0.51
Leased their land	0.04	0.80	0.12	0.66
Migrated to another area	-0.04	0.68	0.29	0.55
Changed from crop to livestock	0.07	0.60	-0.34	0.49
Built a water harvesting scheme	0.08	0.07	0.71	0.51
Irrigated more	-0.33	0.08	0.49	0.35
Eigenvalue (4.76)	2.02	1.55	1.19	-
% of variance explained (52.89)	22.45	17.20	13.23	-

Kaiser-Meyer-Olkin Measure of Sampling Adequacy, 0.601; Bartlett's Test of Sphericity significant at 1%; method: varimax rotation.

Table 3. Factor loadings and communality for adaptation strategies to cope with long-term shift in rainfall in Eastern Region (n = 240).

Items	Leasing out land	Changing crop variety	Soil conservation	Communality
Leased their land	0.90	0.19	0.07	0.85
Migrated to another area	0.85	0.12	0.03	0.73
Changed from crop to livestock	0.69	.01	-0.12	0.48
Increased number of livestock	0.56	0-.03	0.26	0.38
Changed crop variety	-0.05	0.75	0.16	0.59
Reduced the number of livestock	0.19	0.66	0.18	0.50
Built a water harvesting scheme	0.14	0.56	0.11	0.35
Invested in Soil Conservation techniques	-0.02	0.34	0.73	0.65
Planted shaded trees	-0.12	0.43	0.61	0.56
Have found off-farm jobs	0.19	0.16	0.56	0.39
Irrigated more	-0.05	0.48	-0.60	0.59
Eigenvalue (6.05)	2.87	1.98	1.20	-
% of variance explained (55.02)	26.10	18.04	10.88	-

Kaiser-Meyer-Olkin Measure of Sampling Adequacy, 0.689; Bartlett's Test of Sphericity is significant at 1%; method: varimax rotation.

component factor one was named soil conservation, two leasing out land, and three water harvesting strategies (Table 2).

The proportion of variance accounted for by the component soil conservation was 22%. Farmers were investing in soil conservation techniques to facilitate adaptation to changes in rainfall. They also planted shaded trees, changed crop variety and found off-farm employment, towards addressing effects of changes in rainfall. The second factor leasing out land, explained 17% of the variance. French beans farmers in Central region leased out land, migrated production activity to other areas and changed from crop to livestock as solutions to the recurrent problem of changes in rainfall. The proportion of variance accounted for by the third factor water harvesting was, 13%. Farmers built a water harvesting scheme in Central region to reduce the effects of challenges occasioned by changes in rainfall.

In Eastern region, three components representing major prevailing climate change adaptation strategies were, extracted from the farmers' responses. These contributed about 55% of the variance. Based on the items loadings, the component factor one was named leasing out of land, two changing crop variety, and three soil conservation strategies (Table 3).

Principal component one, leasing out of land, explained 26% of the variance. Under this strategy farmers were respectively leasing out their land, migrating production activity to other areas, changing crop variety and increasing number of livestock to cope with the adverse effects. Principal component two, changing of crop variety contributed 18% of the variance. Through this

Table 4. Factor loadings and communalities on adaptation strategies to cope with long-term shift in temperature in Central Region (n = 253).

Items	Off-farm Jobs	Water harvesting	Leasing out land	Communality
Have found off-farm jobs	0.75	0.03	0.08	0.57
Reduced the number of livestock	0.65	-0.03	0.11	0.43
Planted shaded trees	0.63	0.24	0.05	0.46
Invested in Soil Conservation techniques	0.61	0.31	-0.05	0.47
Built a water harvesting scheme	-0.14	0.74	0.04	0.56
Changed crop variety	0.37	0.64	0.01	0.55
Increased number of livestock	0.15	0.61	0.04	0.39
Leased their land	0.05	-0.04	0.71	0.51
Migrated to another area	-0.06	0.13	0.70	0.50
Changed from crop to livestock	0.08	0.01	0.51	0.26
Irrigated more	-0.47	0.34	0.11	0.34
Eigenvalue (5.05)	2.40	1.44	1.21	-
% of variance explained (45.90)	21.84	13.06	11.00	-

Kaiser-Meyer-Olkin Measure of Sampling Adequacy, 0.661; Bartlett's Test of Sphericity significant at 1%; method: varimax rotation.

strategy, farmers were changing crop variety by reducing the number of livestock and building water harvesting scheme, to cope with the effect of changes in rainfall. The proportion of the variance explained by principal component three has soil conservation of 11%. The specific items that improved this factor were respectively planting shaded trees and finding off-farm jobs for income.

The study results showed that, soil conservation and leasing out of land were the common climate change adaptation strategies applied by smallholder French beans farmers in both Central and Eastern regions to cope with the effects of changes in rainfall. While water harvesting was more common in central, change of crop variety was more common in Eastern region, as an adaptation strategy to cope with changes in rainfall.

Adaptation strategies to changes in temperature

Regarding responses to changes in temperature, three principal components were extracted in Central and four Eastern regions. These components represented the major adaptation strategies to changes in temperature used by smallholder farmers in the two regions. The extracted principal components in Central region contributed 46% of the variance. Based on the items loadings, the component factor one was named off-farm employment, two water harvesting and leasing out land strategies (Table 4).

The proportion of variance accounted for by the component off-farm jobs was 22%. French beans farmers in Central region sought off-farm jobs, reduced the number of livestock, planted shaded trees and invested in soil conservation techniques towards coping with the effects of changes in temperature. The second factor water harvesting, contributed 13% of the variances. Under this strategy, farmers built water harvesting schemes, changed crop variety and increased number of livestock kept. The third factor leasing out of land, explained 11% of the variance. Through this strategy farmers leased out their land, migrated production activity to other areas and changed from crop to livestock activity.

In Eastern region, four principal components extracted from the farmers' responses explained 61% of the variation. These components were summarized as soil conservation, irrigation, leasing out land, and livestock rearing (Table 5). The proportion of variance accounted by factor, one soil conservation was 23%. Through soil conservation strategy, farmers invested in soil conservation techniques, planted shaded trees, reduced the number of livestock and found off-farm jobs to cope with the effects of changes in temperature. The second factor irrigation contributed 15% of the variation. The farmers irrigated more changed crop variety and built water harvesting scheme to address the effects of changes in temperature on their French beans production activity. The third factor leasing out land explained 13% of the variation. Under this strategy farmers leased out their land and migrate their production activity to other areas. The fourth factor livestock rearing contributed 10% of the variation. Under this strategy, farmers increased the number of livestock and changed from crop to livestock as means of coping with the effects of changes in temperature in Eastern region.

The study results revealed that the common climate change adaptation strategies used in the two regions in

Table 5. Factor loadings and communalities on adaptation strategies to cope with long-term shift in temperature in Eastern Region (n = 241).

Items	Soil Conservation	Irrigation	Leasing out land	Livestock rearing	Communality
Invested in Soil Conservation techniques	0.82	0-.06	-0.03	0.22	0.72
Planted shaded trees	0.75	0.14	-0.11	0.16	0.61
Reduced the number of livestock	0.50	0.36	0.15	-0.20	0.43
have Found off-farm jobs	0.59	-0.12	0.30	-0.12	0.47
Irrigated more	-0.22	0.81	-0.09	-0.004	0.71
Changed crop variety	0.49	0.59	0.07	-0.19	0.63
Built a water harvesting scheme	0.22	0.56	0.08	0.35	0.49
Leased their land	0.12	0.00	0.83	0.01	0.70
Migrated to another area	-0.03	0.03	0.80	0.22	0.69
Increased number of livestock	0.22	-0.15	0.02	0.75	0.63
Changed from crop to livestock	-0.17	0.22	0.24	0.70	0.62
Eigenvalue (6.70)	2.50	1.62	1.43	1.15	-
% of variance explained (60.93)	22.74	14.76	13.00	10.43	-

Kaiser-Meyer-Olkin Measure of Sampling Adequacy, 0.619; Bartlett's Test of Sphericity significant at 1%; method: varimax rotation.

response to changes in temperature was leasing out land. While off-farm employment and water harvesting strategies were common in central region, soil conservation, irrigation and livestock rearing were common strategies to farmers in Eastern region. The distinct feature revealed by these results was that, smallholder French beans farmers' intention with the prevailing adaptation strategies seems to be in line with those found by other studies. As highlighted by Chiotti et al. (1997) and de Loë et al. (1999), these farmers change crop varieties to the ones that are recommended for higher drought or heat tolerance to increase farm efficiency in circumstances of changing temperature and moisture stress. They also change from crop production to livestock rearing that may tolerate increased changes in climatic conditions (Delcourt and Van kooten, 1995). These farmers seem to undertake soil conservation practices as an adaptation strategy in order to conserve moisture and nutrients (Hucq et al., 2000). Implementing irrigation practices and water harvesting are aimed at, enhancing the production under climate related changes to ensure continued economic benefits (Klassen and Gilpen, 1998). Looking for off-farm employment and leasing out land are employed by farmers to diversify income sources to reduce vulnerability to climate related income loss (de Loe et al., 1999). These strategies should therefore be considered by stakeholders in efforts to enhance adaptation to both changes in rainfall and temperature in the study area.

Factors influencing farmers' adaptation strategies

The study analyzed the influence of socio-economic factors such as Global-GAP policy compliance on the identified climate change adaptation strategies. The results of the maximum likelihood-binary logit estimates for factors influencing adoption of the identified adaptation strategies are presented in Table 6.

The results suggest that Global-GAP compliance significantly promotes adoption of changing crop variety, water harvesting and soil conservation as adaptation strategies to climate change. It also tends to be associated with off-farm employment among complying farmers as an adaptation strategy to climate change. The Global-GAP policy complying French beans farmers have a probability of 3.743, 4.174, 8.949 and 2.720, respectively of adopting changing crop variety, water harvesting, off-farm employment and soil conservation as adaptation strategies to climate change, compared to those who do not comply. This conclusion is drawn based on the positive sign of the marginal effect and the significant level of compliance with, Global-GAP. The results show that, the effect of Global-GAP policy compliance was higher on adoption of off-farm employment, as an adaptation strategy to climate change. As observed by Okello et al. (2007), this implies that the requirements for adapting to other strategies like changing of crop variety, irrigating more and soil conservation under Global-GAP policy requires more capital which the farmer may not be having and hence, they tend to seek this from off-farm employment.

Perception of reduced rainfall among farmers, have a strong positive influence on their adoption of increased irrigation as an adaptation strategy to climate change. This means that as suggested by Hassan and Nhemachena (2008), the drier it gets the higher the demand for more irrigation, among French beans farmers. On the other

Table 6. Factors influencing smallholder French beans farmers' adoption of climate change adaptation strategies.

Items	CCV	WH	IM	OFJ	SC
Region	0.012	1.644***	0.733***	0.693*	1.116***
Gender	0.069	0.015	0.055	0.470	-0.165
Extension	0.889**	0.649	0.026	2.457***	1.316***
Experience	-0.006	-0.005	0.010	-0.029*	-0.004
Weather information	-0.308	-1.578	-3.048***	1.059*	1.321***
Plot size	0.017	-0.322	0.840*	-0.352	-0.505
Soil fertility	0.177	0.086	0.236	0.120	0.154
Wealth	0.033	0.018	0.005	0.010	-0.017
Market distance	0.032	-0.047	-0.103*	0.015	-0.001
Credit	0.198	0.232	0.173	0.006	-1.079***
Land ownership	0.440	-0.869	-0.694	-1.161*	0.694
Household size	0.026	-0.004	-0.119**	0.184*	0.041**
Global-GAP	3.743***	4.174**	1.340	8.949***	2.720**
Reduction in rainfall	-0.068	0.068	0.511***	-0.443***	-0.256**
Increase in temperature	0.803***	0.641**	0.550***	-0.334	0.799***
Constant	1.841***	3.730***	0.445	2.503***	2.670***
Observations	616	616	616	616	616
Chi-square	55.741	62.518	118.004	63.512	116.654
p-value	0.000	0.000	0.000	0.000	0.000
Pseudo R-squared	0.076	0.141	0.140	0.174	0.165

CCV – changing crop varieties; WH – water harvesting; IM- Irrigating more; OFJ – off-farm jobs; SC – soil conservation; Note: *, ** and *** implies statistically significant at 10%, 5% and 1% respectively.

hand, farmers who perceive increase in rainfall tend to adopt off-farm employment and soil conservation as adaptation strategies to, climate change in the study area. Similarly, the study results indicate that perception of increased temperature among French beans farmers positively and significantly influence the adoption of water harvesting, irrigation and soil conservation as adaptation strategies to climate change. This implies that, perception of increased temperature tends to trigger the fear of losing the crop and the expected benefits and hence, most farmers adopt increased irrigation, water harvesting and soil conservation to sustain crop water requirement and to minimize moisture loss.

The study results suggest that farmers with large plot sizes tend to adopt increased irrigation as an adaptation strategy to climate change. This could be linked to the fact that as the size of investment increases most farmers tend to internalize the risks posed by climate change and hence adopt increased irrigation strategy, to ensure that the produce and returns are not lost. The study further suggests that farmers with smaller families tend to adopt increased irrigation as an adaptation strategy to climate change. This was contrary to the expectation that, increased irrigation requires more labour supply from the household members. This could be explained by the fact that French beans production is becoming more specialized due to the costs involved and more smallholder farmers would rather hire experienced casuals to irrigate their farms at the times of need. This is further confirmed by the study results that showed that, farmers with larger household sizes tend to adopt off-farm employment and soil conservation as adaptation strategies. While off-farm employment promotes households' income diversification, the more the members engaged in it the better adoption of soil conservation, as adaptation strategy is quite labour demanding and hence farmers with larger household sizes are advantaged.

Better access to extension seems to have a strong positive influence on the probability of adopting changing crop variety, off-farm employment and soil conservation as adaptation strategies to climate change. This means that through extension services farmers may be obtaining information on income sources diversification and the need to manage well the soils improved production and productivity. On the other hand, long distances to the market tend to significantly improve adoption of increased irrigation as an adaptation strategy to climate change. This was contrary to the expectation and could be explained by the fact that water is critical in the production of French beans and most water sources which are streams are far away from the market. Hence despite the need for proximity, market farmers will still go nearer to the water sources to undertake production of French beans.

Farmers with access to weather information tend to adopt off-farm employment and soil conservation as climate change adaptation strategies. This implies that based on availed weather information, these farmers are able to assess the risks and hence opt to adopt off-farm employment, in order to diversify the income sources. They also opt to conserve soil, to preserve the soil moisture for increased production in the face of changes in climate and weather variability. On the other hand, farmers without access to weather information are more likely not to adopt increased irrigation as climate change adaptation strategy. This is contrary to the expectation.

Farmers, who have access to credit, tend to adopt soil conservation in farms more than those who do not have access to credit. As expected, access to credit increased the likelihood of adaptation of irrigation as an adaptation strategy. As reported by Gbetibouo (2009) and O'Brien et al. (2000) in Tanzania, despite numerous adaptation options that farmers are aware of and willing to apply, access to credit is crucial in adaptation of soil conservation strategies.

The more experienced French beans farmers are, more likely to adopt off-farm employment as an adaptation strategy to climate change. This implies that experience enables the farmer to assess and adopt off-farm employment for improved income diversification, in the face of climate change. Experienced farmers have an increased likelihood of adopting off-farm employment, as an adaptation strategy. These results confirm the findings of Nhemachena and Hassan (2007) in a similar study of adaptation in the Southern Africa region. Experienced farmers have high skills in farming techniques and management and are more likely to spread risk when faced with climate variability.

The study results revealed that, whereas soil conservation and leasing out of land are common adaptation strategies to changes in rainfall and temperature, there are also region-specific strategies, which defines French beans farmers' response to climate change risks. This implies that to support development of more efficient and effective climate change adaptation strategies in the fruit and vegetables farming, research should appreciate regional or sub-regional diversity in farmers' responses. This validates the findings of Smithers and Smit (1997) and Smit and Skinner (2002) that, adaptation in agriculture is defined by various spatial scales including plant, plot, farm, region and nation. The findings further implied that, there are differences in level of complexity and requirements to adopt the various strategies used in each region. For instance, while water harvesting, soil conservation, change of crop variety are more strategic adaptation strategies to changes in rainfall and temperature and require longer-term, others like looking for off-farm jobs are a bit tactical and requires shorter-term to adopt. This corroborate the findings of Smit et al. (1996), that short-term adaptation strategies might include, adjustments made within a season like looking for off-farm jobs and irrigation while longer-term adaptation strategies might involve structural changes in the management that would apply in subsequent seasons like water harvesting, taking up livestock rearing, and soil conservation. This further implies that, resource endowment and capacities should be some of the key considerations in identifying climate change adaptation strategies in other to promote among smallholder French beans farmers, in each specific region.

In addition, the results revealed that food safety and environmental policies enforced by private sector players such as Global-GAP standards, plays an important role in enhancing adoption of climate change adaptation strategies in smallholder fresh fruit and vegetables farming. As suggested by Smit and Skinner (2002), it is therefore important for the policy makers and stakeholders to evaluate and recognize the specific roles played by such private policies, with respect to adaptation in order to enhance adoption of response strategies. This is validated by Bryant et al. (2000) and Bryant (1994)'s assertion that, farmers make adaptation decisions in the context of prevailing policy, economic conditions, financial systems, and social norms. Hence other significant variables identified by this study as, influencing farmers' decisions on adaptation of specific strategies like region, extension, weather information, plot size, market and credit access, reduction in rainfall and increase in temperature should also be considered by the policy-makers and stakeholders in the measures designed, to enhance adoption of climate change adaptation strategies in fruit and vegetables farming.

Conclusions

The study analyzed the French beans producing farmers prevailing climate change adaptation strategies and the factors affecting their adoption in Central and Eastern regions of Kenya using factor analysis and binary logit regression model. The adaptation strategies of the farmers identified, using factor analysis include soil conservation, water harvesting, off-farm employment, leasing out of land, changing crop variety, irrigation and livestock rearing. The common study area-wide adaptation strategies to climate change were found to be soil conservation and leasing out land.

The empirical results of the logistical regression model showed that, Global-GAP policy compliance significantly and positively increased the probability of the farmers to undertake changing crop variety, water harvesting, finding off-farm jobs and soil conservation as adaptation strategies to climate change. Other identified factors like access to extension, region of the farmer, access to credit, access to weather information, distance to the market, household size, plot size, and perception on reduction in rainfall and increase in temperature, should be included in climate change adaptation strategies promotion, to enhance adoption of adaptation strategies. The policy implication of this study is that, the government and service providers should mainstream such factors as Global-GAP compliance and regional considerations among other factors, which enhance the probability of adopting adaptation strategies to climate change related projects and programmes in the smallholder fruits and vegetables farming sector.

However, the study did not investigate the effect of area-wide prevailing adaptation strategies on the French beans productivity performance among farmers due to lack of information. There is need for further research to probe for example the effect of leasing out of land activities of smallholder French beans farmers which the study found to be common prevailing adaptation strategy on productivity performance. Future research should endeavor to investigate this further, the economic status of farmers who have leased out land, since leasing out of land is hypothetically seen to diminish the area under French beans especially, if the land is converted to totally different activities.

CONFLICTS OF INTEREST

The authors have not declared any conflict of interests.

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Adjustment of decay rates of organic matter in a *Latossolo Vermelho-Amarelo* in the Araripe National Forest, Brazil

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The use of mathematical models is an alternative way to understand how management practices affect soil organic matter (SOM) dynamics because such models yield results on time scales that would be impossible to observe in field studies. The aim of this study was to parameterise and calibrate the application *Century* 4.0 in terms of the edaphoclimatic conditions of a *Latossolo Vermelho-Amarelo* of the Araripe Plateau and simulate the soil C dynamics in each compartment. The study was conducted in the Araripe National Forest (Floresta Nacional do Araripe — FLONA). The soils are classified as Latossolos Vermelho-Amarelos with a medium clayey texture and a clay fraction consisting of kaolinite with iron and aluminium oxides. The physical and chemical properties of the soils were obtained at a depth of 0.00-0.20 m in 2012 and 2013. The best total organic carbon (TOC) result was an error of only 3% between the measured and simulated values, which was obtained with a PRDX (4) adjustment of 140 g m^{-2} C. After correcting for the C decay rate in the passive (PC), slow (SC) and active compartments (AC), absolute errors lower than 10% were obtained for the C values. The abiotic correction factors specific to each compartment were 0.89 for the active and passive compartments and 1.12 for the slow compartment. The sensitivity analysis indicates that all compartments are sensitive to variations in maximum and minimum temperature and that the clay content affects the TOC and the passive compartment.

Key words: *Century* model calibration, soil carbon compartments.

INTRODUCTION

Stocks of soil organic matter (SOM) are sensitive to cultivation practices, land-use conversions, mineralogy and edaphoclimatic conditions of a region, all of which affect its long-term balance and decomposition (Lin et al., 2014). Thus, one of the possible reasons for reduction of carbon stocks in soil compartments involves changes in the organo-mineral interactions in soils exposed to weathering.

Soils with a high degree of weathering such as the Latosols (predominance of low-activity clays) are very dependent on organic matter to maintain adequate function and sustainability (Silva and Mendonça, 2007).

The use of mathematical models is an alternative approach to understanding how management practices affect the SOM dynamics in that such models yield results on time scales that would be impossible to observe in field studies.

Several mathematical models have been developed to address the SOM distribution in compartments with various soil decay and permanence rates, that is, active (rapid cycling), slow (intermediate) and passive (slow) rates. One example is the *Century* model, which was developed for temperate climate soils (Parton, 1996; Segoli et al., 2013). The proposed model is used to classify the SOM into compartments of decreasing rates that follow first-order kinetics.

Century has been successfully used to simulate SOM dynamics on decadal time scales, which are affected by inputs of organic matter and environmental controls such as temperature and humidity. Therefore, it is necessary to calibrate the model for soils in different climates. This calibration involves, among other actions, the adjustment of abiotic factors that correct the decay constants of the various compartments.

Another aspect to be considered in the SOM dynamics is the effects of the fine-particle fractions (clay and silt) and the mineralogic aspects of the clays (Van Veen and Paul, 1981). However, these mineralogic aspects are not taken into account in *Century*, which can lead to an underestimation of SOM in the passive compartment of soils containing 1:1 clays, such as kaolinites, and abundant iron and aluminium oxides, which are primarily responsible for SOM stability in microaggregates (Sollins et al., 1996). In *Century*, this stabilisation is taken into account by adopting an “aggregation factor” for the passive compartment.

Given the above issues and a lack of data regarding SOM stabilisation in kaolinitic soils in semi-arid regions, the assumptions made in this study are: The reduction of carbon storage in the soil compartments is a result of changes in organo-mineral interactions in the elements exposed soils e the century application allows to evaluate the dynamics of organic matter in soils subjected to cutting shallow type of native vegetation in semiarid region. The assumptions made in this research are: The reduction in the stock of carbon in the soil compartments is a result of changes in organo interactions in the weather exposed soils and Century Application allows evaluation of the dynamics of organic matter in soils subjected to the cut (shallow type) of native vegetation in semi-arid region. The aims of this study were to parameterise and calibrate *Century* 4.0 for the edaphoclimatic conditions of a Latossolo Vermelho-Amarelo of the Araripe Plateau, in northeastern Brazil, and to simulate the C dynamics in each compartment of this soil.

MATERIALS AND METHODS

Location and characterisation of the study area

The study was conducted in the Araripe National Forest (FLONA-Araripe), located in the eastern part of the Araripe Plateau, in the extreme southern part of the state of Ceará. The study area was bounded by latitudes 9183896 and 9199039 N and longitudes 435987 and 460703 S, Zone 24S, SAD-69 datum). FLONA-Araripe has an area of approximately 383 km^2 and is at an elevation of approximately 1,000 m. The topography is generally flat aside from prominent cliffs on the northwest, and the relief is approximately 400 m (Alves et al., 2011).

Vegetation in FLONA-Araripe consists primarily of semi-evergreen rain forest and savannah (“cerradão”). However, the species *Nectandra cuspidata* Ness, commonly known as *louro urubu,* predominates in the study area.

The regional climate is of the Aw’ type, that is, tropical and rainy, with mean annual maximum and minimum temperatures of 34 and 18°C and a mean annual rainfall of 1,033 mm. The monthly mean values are distributed as shown in Figure 1. These data were obtained from the Brazilian National Institute of Meteorology (Instituto Nacional de Meteorologia) (Inmet, 1993).

The soils consist primarily of Latossolo Vermelho-Amarelo (EMBRAPA, 1999) with a clayey texture and containing iron and aluminium oxides; the clay fraction consists of kaolinite. The characterisation was performed by fluorescence and X-ray diffraction with spectral interpretation using the application *X’PERT HighScore Plus* (PW3212).

The physical (texture and density) and chemical (C content and pH) properties of the soils at a depth of 0.00-0.20 m and their respective analytical methods and references are presented in Table 1.

The composite sample for the analyses of the physical and chemical properties of the soils was prepared by homogenising a mixture of five simple samples collected with a Dutch hand auger in 2012 and 2013. The simple samples were collected in a zigzag pattern within a 200-m radius from random georeferenced points. Before the analytical procedures, the composite sample was air dried, crushed and passed through 2-mm mesh sieves.

The climate parameters (Figure 1) and physical and chemical properties of the soils (Table 1) were used in the calibration and sensitivity analysis of the SOM dynamics model in *Century* 4.0 (Parton et al., 1987).

Mathematical model of carbon dynamics

The SOM dynamics are evaluated in various cycling times in *Century*: fast (1 to 5 years), intermediate (20 to 40 years) and slow (200 to 1,500 years), which represent the active, slow and passive compartments, respectively.

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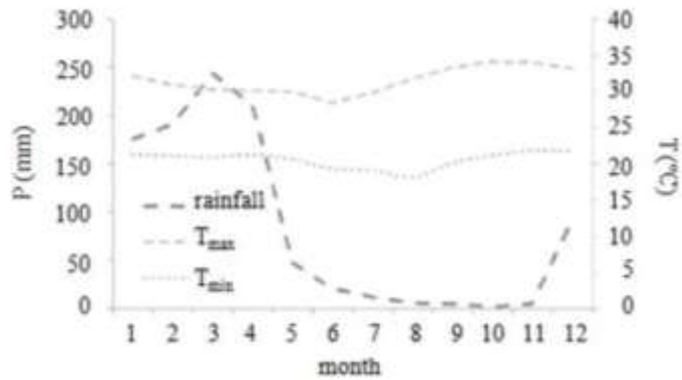


Figure 1. Monthly mean maximum and minimum temperature and rainfall values.

Table 1. Physical and chemical properties of the soils and their respective analytical methods and references.

Property		Method	Reference
		Physical	
Particle size (-)			
Sand:	0.46	Pipette	- Embrapa (1997)
Silt:	0.16		
Clay:	0.38		
Density ($g.cm^{-3}$):	0.80	Volumetric ring	
		Chemical	
C content ($mg.m^{-2}$)			
TOC:	5,948.8	Oxidation with potassium dichromate	- Adapted from Yeomans and Bremner (1988)*
Passive C:	2,864.0	Differential solubility	- Adapted from Swift (1996)*
Slow C:	2,968.3	Water flotation	- Adapted from Anderson and Ingram (1989)*
Active C:	116.5	Irradiation - extraction	- Adapted from Islam and Weil (1998) and Brookes et al. (1982)*
pH (-):	4.47	Potentiometric	- Embrapa (1997)

*Cited in Mendonça and Matos (2005).

An assessment of the SOM dynamics was conducted based on the C decay rate in the various soil compartments, which is affected by climate factors (humidity and temperature), edaphoclimatic factors (aerobiosis and availability of nutrients) and soil management practices. According to Parton et al. (1987), *Century* incorporates the effects of these factors in the first-order decay kinetics to model the SOM dynamics (Equation 1):

$$dC_i/dt = -K_i C_i, \quad (1)$$

where dC_i/dt is the C decay rate in the *i-th* soil compartment, K_i is the decay constant, and C_i is the C concentration.

There are eight soil compartments: surface and soil structural residues (i = 1 and 2, respectively); the active fraction (i = 3); surface microorganisms (i = 4); surface and soil metabolic residues (i = 5 and 6, respectively) and the slow and passive fractions (i = 7 and 8, respectively).

In all compartments, the combined effect of moisture (M_d) (expressed in terms of the monthly total rainfall and potential evapotranspiration) and temperature (T_d) (expressed in terms of mean monthly soil temperature) constitutes an abiotic factor (A) (Equation 2) that corrects Equation 1. The potential evapotranspiration and mean temperature of the soil are calculated from the monthly mean maximum and minimum air temperatures using the Linacre equations (Linacre, 1977).

$$A = M_d \, T_d \quad (2)$$

In the surface and soil structural residue compartments (i = 1 and 2), Equation 1 is also corrected by the L_c factor (Equation 3), which is a function of the lignin content (L_s). In the active compartment (i = 3), it is also corrected by the soil texture factor (T_m) (Equation 4), which is a function of the total fraction of silt and clay (T). In this case, because only the active (i = 3), slow (i = 7) and passive (i = 8) fractions are evaluated, the correction factors of the decay kinetics are not due to the lignin content.

$$L_c = e^{-3L_s} \quad (3)$$

$$T_m = (1 \quad T) \quad (4)$$

In the C dynamics, the total C fraction that leaves the active compartment is subdivided into four different flows: microbial respiration (F_T) (Equation 5), leaching of soluble organic carbon C_{LEA} (Equation 6) and C stabilisation in the passive (C_{AP}) (Equation 7) and slow compartments (C_{AS}) (Equation 8). In this process, the carbon derived from the slow compartment is relocated to the passive (C_{LP}) (Equation 9) and active SOM compartments (C_{LA}) (Equation 10). In relocating to the active compartment, it is believed that 55 % of the C is lost by microbial respiration (Leite et al., 2003).

$$F_T = 0.17 - 0.68T \quad (5)$$

$$C_{LEA} = \frac{(H_2\,O)30}{18\,(0.01+0.04T_S\,)} \quad (6)$$

$$C_{AP} = 0.003 + 0.032T_c \quad (7)$$

$$C_{AS} = \,[1 - (C_{AP} - C_{LEA} - F_T] \quad (8)$$

$$C_{LP} = 0.003 - 0.009T_C \quad (9)$$

$$C_{LA} = 1 - C_{LP} - 0.55 \quad (10)$$

where $(H_2\,O)_{30}$ and 18 are, respectively, the leaching water depth and the critical mineral leaching water depth below a soil depth of 0.30 m, and T_S and T_C are the amounts of sand and clay in the soil, respectively. The leaching water depth is calculated from a simplified water balance.

Calibration of the soil carbon dynamics model, sensitivity analysis and simulation

Century consists of a pre-processor (FILE100, which manages the creation and update of input files, and EVENT100, which creates an event file (.SCH)), a processor (the executable file *Century* (.PLT)) and a post-processor (LIST100, which provides the simulation results).

The model calibration was performed in two steps, considering the equilibrium condition established over 6,000 years in the 0.00-0.20 m layer. In the first step, simulations using the *default* option "Rainforest" were performed by varying the maximum monthly net production of C of the PRDX(4) forest, available in the TREE.100 file of the FILE100 utility, thereby obtaining consecutive TOC and C concentrations in the active, slow and passive compartments. Linear graphs of the "relative error" (E) *versus* PRDX(4) were obtained from the results for each C concentration. The PRDX(4) corresponding to the lowest E of the TOC was estimated from the graphs. In this step, for the same PRDX(4), discrepancies in the C concentrations in each compartment were observed.

In the second step, the PRDX(4) obtained in the first step was fixed, and the decay constants were adjusted in the active (i = 3), slow (i = 7) and passive (i = 8) compartments (DEC3.2, DEC5 and DEC4 of the FIX.100 file of the FILE100 utility, respectively). In this step, linear graphs of the C concentration in each compartment *versus* DEC5, DEC4 and DEC3.2 were obtained. Adjusted decay constants (K_i^*) were obtained from the graphs, corresponding to the lowest E values of the C concentrations in each compartment.

The characteristic correction factor *A** for the study area was obtained based on the adjusted decay constants in each compartment (K_i^*: DEC3.2, for i = 3, DEC5, for i = 7 and DEC4, for i = 8), using Equation 11, and considering the *default* values of the FIX.100 file as a reference (K_i: 7.3 year^{-1}, for i = 3, 0.2 day^{-1}, for i = 7 and 0.0045 year^{-1}, for i = 8).

$$K_i^* = A^*.K_i \quad (11)$$

A sensitivity analysis was performed by evaluating the absolute values of the angular coefficients (a) of the slopes obtained in each step of the calibration (high values of a indicate greater sensitivity of the model to the parameter evaluated in a given compartment). A sensitivity analysis was also performed for the variables T_{max}, T_{min} and the clay fraction.

Based on the adjusted values of PRDX(4), DEC3.2, DEC5 and DEC4, the C dynamics were simulated in the 0.00-0.20 m layer, considering an equilibrium condition established over 6,000 years.

The data were subjected to an analysis of the correlation coefficient using the Microsoft Excel data analysis tool.

RESULTS AND DISCUSSION

Calibration of *Century*

Figure 2 (A) shows that the best result for the TOC was obtained for a PRDX(4) of 140 g m^{-2} C because the discrepancies between the measured and simulated values generated an error of only 3%. However, for this PRDX, there was an overestimation of C in the slow compartment (16.7%) and an underestimation in the active and passive compartments (9.6 and 10%, respectively).

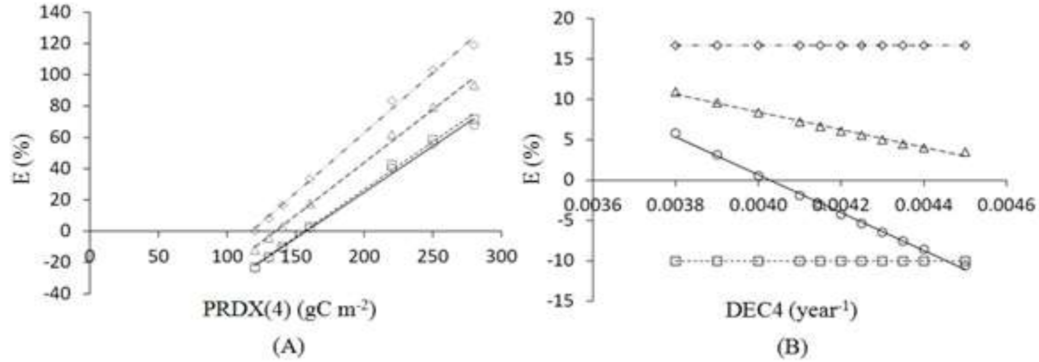
The underestimation of the TOC in the passive compartment is consistent with the results obtained by Silva and Mendonça (2007). According to these authors, the underestimation in the passive compartment in tropical soils dominated by kaolinite arises from the interference of the Fe and Al contents in the stabilisation of SOM.

The stated that the high stability of the organo-minerals arises from the electrostatic interaction of the positive charges of the Fe and Al oxides and the negative charges of the SOM, thereby hampering microbial access to the organic substrate. The oxides are responsible for the disorganisation of the clay particles on a microscopic scale, thus hampering the face-to-face orientation of the kaolinite crystals. This disorientation prevents the formation of the deoxy plasma and favours the onset of the formation of the granular structure, which ensures greater resistance to anthropogenic interference and to changes in soil management (Silva and Mendonça, 2007).

The X-ray diffractogram (Figure 3) shows intense peaks that identify the X-ray powder diffraction pattern of Kaolinite-Aluminum Silicate Hydroxide ($Al_2Si_2O_5$ $(OH)_4$), Silicon Oxide (SiO_2), Titanium Oxide (TiO_2) and Goethite-Iron Oxide Hydroxide ($FeO(OH)$).

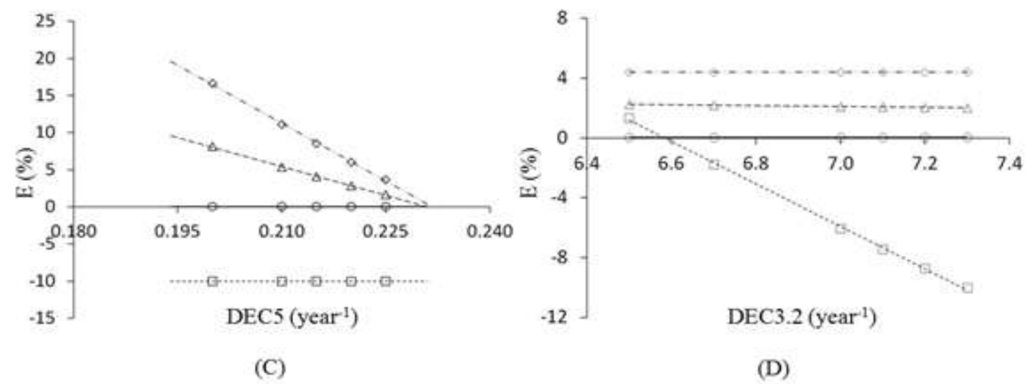
The distribution of the chemical elements identified in the x-ray fluorescence analysis confirms the diffraction results because the quantities shown add up to quantities that constitute the abovementioned clay type and minerals: the amounts of silicon oxides (SiO_2), aluminium oxides (Al_2O_3), iron oxides (Fe_2O_3) and titanium oxides (TiO_2), were respectively, 28.268, 19.717, 44.867 and 5.3415%.

Another aspect to be considered is that according to Gatto et al. (2010), the Latosols, which comprise the soils of the study area, generally display a high degree of clay flocculation, which provides greater physical protection of the TOC due to the formation of organo-minerals less



Legend:	R^2	a ($gC^{-1}\ m^2$)	E (%) (PRDX(4) = 40 gC m^{-2})
TOC (Δ)	1.00	0.765	3.0
AC (□)	1.00	0.587	-9.6
PC (○)	1.00	0.606	-10.0
LC (◊)	1.00	0.676	16.7

Legend:	R^2	a (year)	E (%) (DEC4 = 0.00402 $year^{-1}$)
TOC (Δ)	0.99	-10,975.7	8.0
AC (□)	0.00	0.000	-10.0
PC (○)	1.00	-23,495.9	-0.3
LC (◊)	0.00	0.000	17.0



Legend:	R^2	a (year)	E (%) (DEC5 = 0.22346 $year^{-1}$)
TOC (Δ)	1.00	-259.239	2.0
AC (□)	0.00	0.000	-10.0
PC (○)	0.00	0.000	0.0
LC (◊)	1.00	-519.540	4.0

Legend:	R^2	a (year)	E (%) (DEC3.2 = 6.5 $year^{-1}$)
TOC (Δ)	1.00	-0.285	2.3
AC (□)	1.00	-14.212	1.3
PC (○)	0.00	0.000	0.0
LC (◊)	0.00	0.000	4.4

Figure 2. Relative error (E) of the TOC and C concentrations in the active (AC), passive (PC) and slow (LC) compartments *vs.* PRDX (4) (A), DEC4 (B), DEC5 (C) and DEC3.2 (D). R^2: coefficient of determination; a: angular coefficient of the slope.

prone to decomposition. In the C dynamics, clay acts as a binder, protecting the organic C in the soil from heterotrophic decomposition. The type of clay may also affect the physical protection capacity, due to the effect of colloidal protection of the organic material. Soils with clays of greater specific surface area (SSA), such as smectite and vermiculite (2:1) with an SSA of 800 $m^2\ g^{-1}$, adsorb greater amounts of humic substances than soils with clay of lower specific surface area, such as kaolinite, which has an SSA of approximately 39 $m^2\ g^{-1}$ (Dixon, 1977).

The authors therefore conclude that the absence of mineralogical aspects in the SOM dynamics model in *Century* can lead to underestimation in the passive compartment in soils with kaolinite and Fe and Al oxides, as observed in this study.

There was also underestimation of the C in the active compartment, as shown in Figure (2e), by a relative error of 9.6%. There was underestimation (17%) of the C stock values in the active compartment, claiming that this result

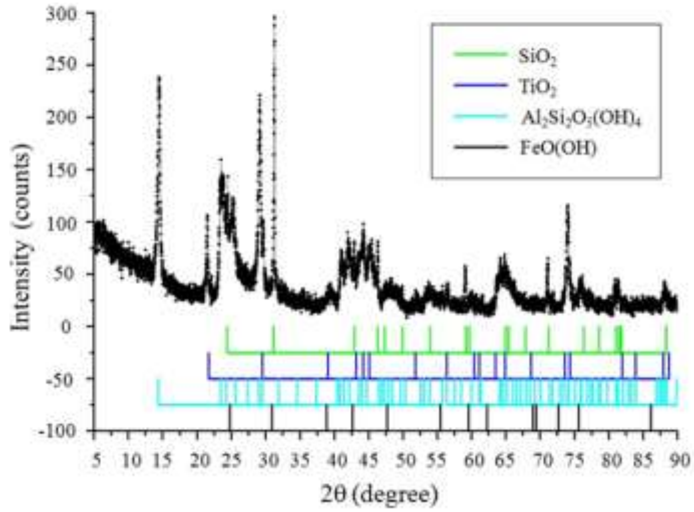


Figure 3. X ray diffractogram of the clay fraction. Ɵ: x ray incidence angle; Kt: kaolinite.

Table 2. Decay constant (K), adjusted constant (K*) and correction factor (A*) of the carbon decay rate in the passive (DEC4), slow (DEC5) and active (DEC3.2) compartments.

Parameter	K ($year^{-1}$)	K* ($year^{-1}$)	A*
DEC4	0.0045	0.00402	0.89
DEC5	0.2000	0.22500	1.12
DEC3.2	7.3000	6.50000	0.89

may be attributed to the absence in the model of the mechanisms controlling the exudation of C through the roots, of microbial metabolism in soils with intense organic fertilisation and the influence of the soil (Leite et al., 2004).

After correction of the C decay constants (K) in the passive (DEC4), slow (DEC5) and active compartments (DEC3.2), correction factors (A) were obtained, as shown in Table 2. This procedure was performed until absolute errors for the TOC values lower than 10% were obtained.

In Figure 2b, while maintaining the PRDX(4) (Figure 2a) constant, it was observed that the adjustment of the C decay constant in the passive compartment (DEC4) from 0.0045 to 0.00402 $year^{-1}$ decreased the discrepancies between the humic substance concentrations obtained experimentally and the simulated concentrations, thereby generating an error of only 0.04%, which is considered optimal for the study area. In contrast, this reduction in the K value decreased the C decay rate, resulting in increased TOC concentrations, with a consequent increase in the error between the measured and simulated values (from 3 to 8%). It is important to note that the reduction of the decay constant of the passive compartment in this study is justified by the mineralogy of the study area because the iron and aluminium oxides and kaolinite predominate in the FLONA soil and are responsible for the physical and colloidal protection of the SOM. This protection makes the SOM inaccessible to microorganisms and contributes to the formation of microaggregates (Sollins et al., 1996).

Another aspect to be considered refers to the fact that the adjustment of the K of the active compartment did not change the C concentrations in the active and slow compartments, showing that DEC5 and DEC3.2 are not sensitive to the DEC4 decay constant.

The lowest errors related to the LC concentration (3.7%) and TOC (1.7%) in the slow compartment (DEC5) (Figure 2c) were obtained by raising the K value from 0.20000 to 0.22500 yr^{-1} (Table 2). For DEC3.2, the lowest errors, that is, 2.3% for the TOC and 1.4% for the carbon of the active compartment were obtained when reducing K from 7.3 to 6.5 yr^{-1}.

Thus, the adjustments of the decay constants corrected the underestimations of the C concentrations in the active and passive compartments and the overestimation in the slow compartment. These adjustments also altered the value of the combined effect of temperature and moisture (A), which was assumed to equal to 1 in all compartments by default in *Century*. After the K adjustments, the A correction factors specific to the study area, herein represented by A*, were 0.89 for the active and passive compartments and 1.12 for the slow

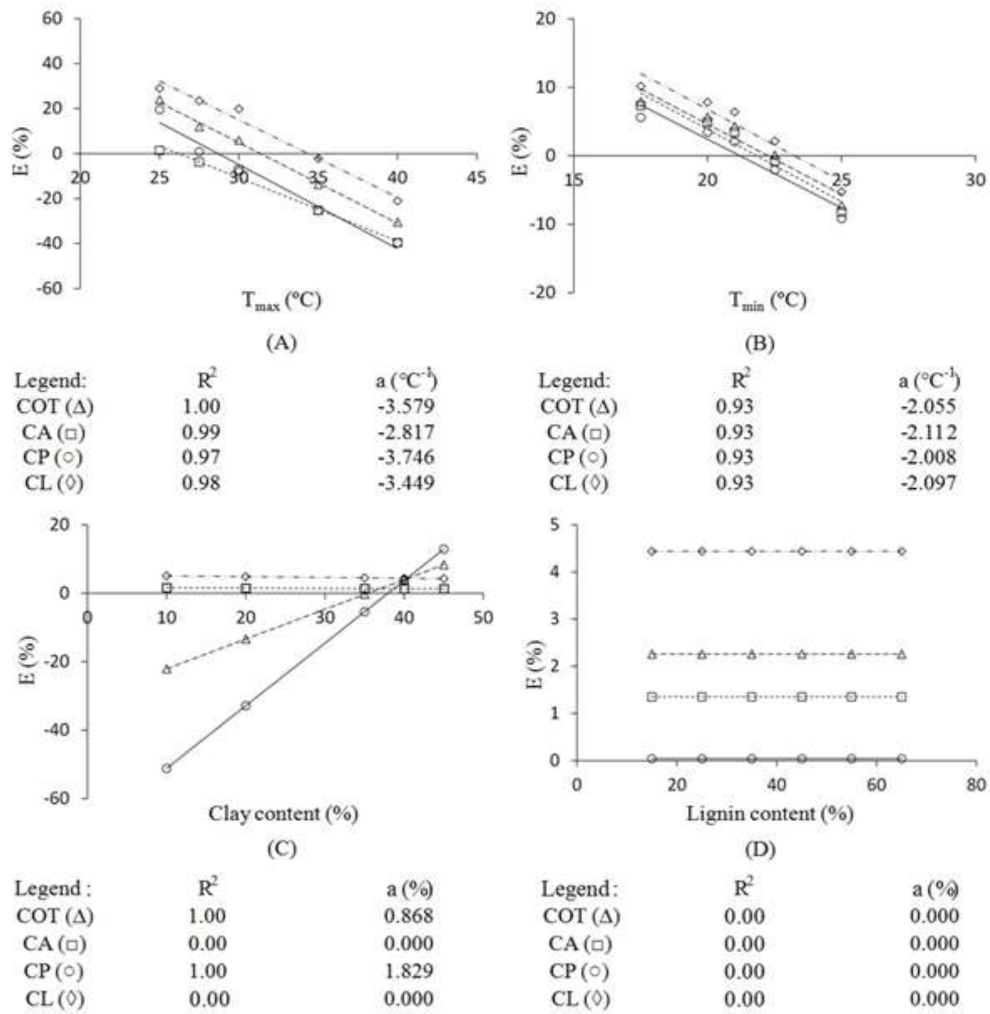


Figure 4. Relative error (E) of the TOC and C concentrations in the passive (C_{PC}), slow (C_{SC}) and active (C_{AC}) compartments *vs.* maximum temperature (A), minimum temperature (B), clay content (C) and lignin content (D). R^2: coefficient of determination; a: angular coefficient of the slope.

compartment (Table 2). These results initially suggest a greater decay rate of the organic matter in the slow compartment, that is, the opposite of the expected decay rates of organic matter in the three compartments: high in the slow compartment, intermediate in the active compartment and low in the passive compartment.

However, the fact that A* is greater in the slow compartment may be attributed to the input of materials of slow biodegradation (such as lignin) from the structural compartments of the shoot and root. In this case, to compensate for the effect of the type of material allocated in this compartment such that the organic matter decay rate is intermediate compared to those of the other compartments, it is indeed necessary for the combined effect of temperature and moisture to be greater. In fact, the slow compartment includes other compounds in addition to C from the light fraction, with characteristics that result in an increase of the abiotic factor (Motavelli et al., 1994).

Sensitivity analysis

A sensitivity analysis was conducted after adjusting all parameters (Figure 4). The variations in the stocks of total organic C and C contents in the active, slow and passive compartments with temperature corroborate the results obtained by Leite et al. (2004). In that study, using *Century*, the author noted that changes in air temperature led to a 20% increase in the TOC stocks. The author also concluded that changes may occur in the output variables (carbon contents in the active, slow and passive compartments) based on changes in the input variables on the order of 10 to 30%.

Figure 4c shows that the clay contents interfere with the TOC and carbon contents in the passive compartment. This behaviour was expected because the organo-mineral interactions characteristic of soils with a predominance of kaolinite and iron oxides promotes physical and chemical protection, thereby hindering the stabilisation of SOM (Parton et al., 1987; Parfitt et al., 1997; Leite et al., 2004).

The environmental conditions in the study area are an important factor in the behaviour of SOM dynamics, particularly in tropical climates (Zech et al., 1997; Tornquist et al., 2009). However, they note that there is little information in highly weathered soils, such as Latosols, containing kaolinite.

None of the variables showed sensitivity to the amount of lignin (Figure 4d), which means that this input variable does not cause major modelling changes.

Based on the above findings, the adjustments in the decay constants and in the correction factors of the combined effect of temperature and moisture (A) in each compartment become essential when attempting to understand the C dynamics in weathered soils of semiarid regions with a predominance of kaolinite and Fe and Al oxides.

There is only one sensitivity analysis in the literature, specifically, the study by Leite (2002), that addresses the effects of the input data on the output variables in the *Century* simulator. However, that study was conducted on soils with different characteristics from the FLONA soil.

Conclusions

The application *Century* was found to have great potential for simulating the C dynamics of soil in semiarid regions with a predominance of kaolinite and iron and aluminium oxides after adjusting the decay constants. These adjustments allow the decay rates of the compartments to adequately simulate conditions in the study area (tropical conditions) because the default conditions in *Century* were developed for temperate climates.

The C in the active and passive compartments is more sensitive to environmental conditions in the study area than is the C in the slow compartment.

The sensitivity analysis revealed that the variables TOC, C_{PC}, C_{SC}, and C_{AC} are sensitive to the input variables of maximum temperature and minimum temperature. The clay contents affect the TOC and carbon contents in the passive compartment. The analysed variables displayed no sensitivity to lignin.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Aluminum buffering in acid soil under mineral gypsum application

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Many researches have performed on gypsum application to correct high exchangeable aluminum content in acidic soils, especially in subsurface. Although, they have found increases in the exchangeable calcium and sulfur contents, exchangeable aluminum has not been decreased. The exchangeable aluminum buffering by organic matter may contribute to non-significant reduction in exchangeable acidity. The objective of this study was to evaluate the effect of mineral gypsum on the aluminum compartments of Hardsetting Ultisol and monitor the capacity of gypsum to provide exchangeable calcium and sulfur in subsurface. Increasing amounts of mineral gypsum (0, 2, 4, 6, and 8 Mg ha^{-1}) were applied with broadcast at the field. The experimental design consisted of randomized block with four replicates. Aluminum compartments (Al-organic matter, Al-amorphous and Al-crystalline) were evaluated at 0 and 15 days after gypsum application and the exchangeable calcium and sulfur contents were evaluated at 0, 15, 64 and 90 days. The evaluations were performed in three different layers. Gypsum application increased the exchangeable calcium and sulfur contents in subsurface and did not reduce the exchangeable aluminum content. Al-organic matter in the surface layers decreased along the incubation time and application gypsum. Al-amorphous in the subsurface layers increased with the increased amounts of gypsum. Al-crystalline decreased as soil depth increased. The exchangeable aluminum buffering in surface layers was performed by Al-organic matter and, in subsurface, by Al-crystalline.

Key words: Aluminum compartments, aluminum fractionation, soil acidity, soil pH, exchangeable calcium.

INTRODUCTION

The soil exchangeable Al determination is not an appropriate indicator for evaluation of the performance of the gypsum on soil exchangeable acidity. Many researches with gypsum application to correct high exchangeable Al content in acidic soils have been performed in Brazil, without the expected success (Saldanha et al., 2007; Rocha et al., 2008; Santos et al., 2013b).

There are reports stating that one of the main actions of gypsum result in the formation of $Al(SO_4)^+$ (Santos et al., 2013b). Most of this complex is leached, but may be a considerable fraction is removed by KCl extractor, making exchangeable Al determination after the gypsum important in the evaluation of soil acidity, because Al in application to be overestimated.

The determination of Al-oxyhydroxides, Al-sulfate

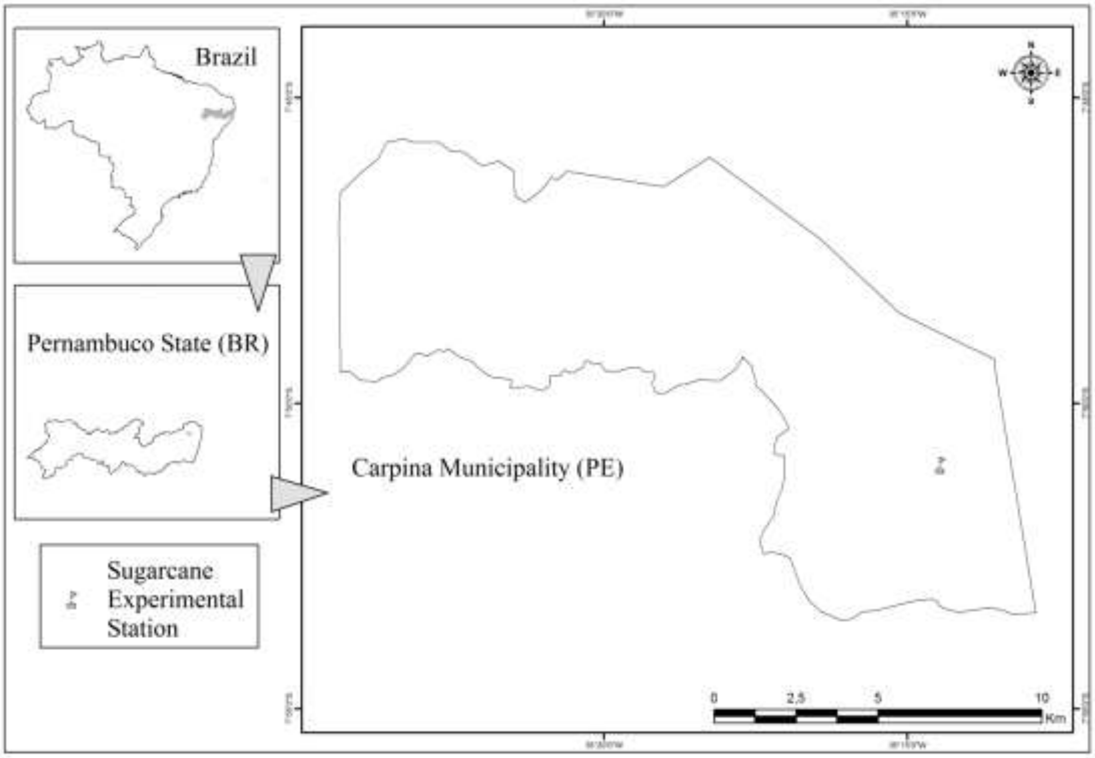

Figure 1. Experimental area localization at Pernambuco State, Brazil.

minerals of low crystallinity and Al-organic matter is very these compartments can buffer the exchangeable Al (Takahashi et al., 2006). Al of these compartments may be converted in exchangeable Al and, depending on the converted amount Al may be toxic to plants.

Gypsum application in the soil can promote modifications in these different Al compartments (Takahashi et al., 2006; Li et al., 2010; Álvarez et al., 2012). This is important because plants have different tolerance to the presence of exchangeable Al in the soil (Reyes-Díaz et al., 2011). Decrease in soil Al contents occurs due to the formation of Al-hydroxides and Al-sulfate minerals of low crystallinity resulting from the gypsum application (Takahashi et al., 2006). These compounds leach to soil deeper layers, distant from the zone of highest absorption by the roots. Childs et al. (1983) claimed that the determination of amorphous Al-oxyhydroxides with solution of ammonium acid oxalate (AAO) satisfactorily estimated the amount of Al-amorphous leached from the soil upper layers.

Thus, techniques that enable the quantification of the Al in different Al-compartments (Al-crystalline, Al-organic matter and Al-amorphous), allow investigating more accurately, the influence of gypsum on Al and its translocation along soil profile.

In this context, this study aimed to evaluate the effect of mineral gypsum application on the Al-compartments of an Hardsetting Ultisol in Pernambuco, Brazil, and monitor the capacity of mineral gypsum to supply exchangeable Ca and S-SO_4^{2-} in subsurface.

MATERIALS AND METHODS

The experiment was installed in the field in January 2012 at Sugarcane Experimental Station of Carpina (EECAC/UFRPE), in Pernambuco, Brazil (Figure 1). The soil was classified as dystro-cohesive Red Yellow Argisol (Santos et al., 2013a), corresponding to Hardsetting Ultisol (Soil Survey Staff, 1998). Soil tillage consisted of harrowing, without limestone application. Five soil samples were collected in the experimental plots, in order to form a composite sample of the layers of 0.0-0.2, 0.2-0.4 and 0.4-0.6 m, for chemical and physical characterization (Donagema et al. 2011) (Table 1).

The treatments corresponded to the application of 0, 2, 4, 6 and8 Mg ha-1 of mineral gypsum (18% of Ca and 23% of S-SO42-) and

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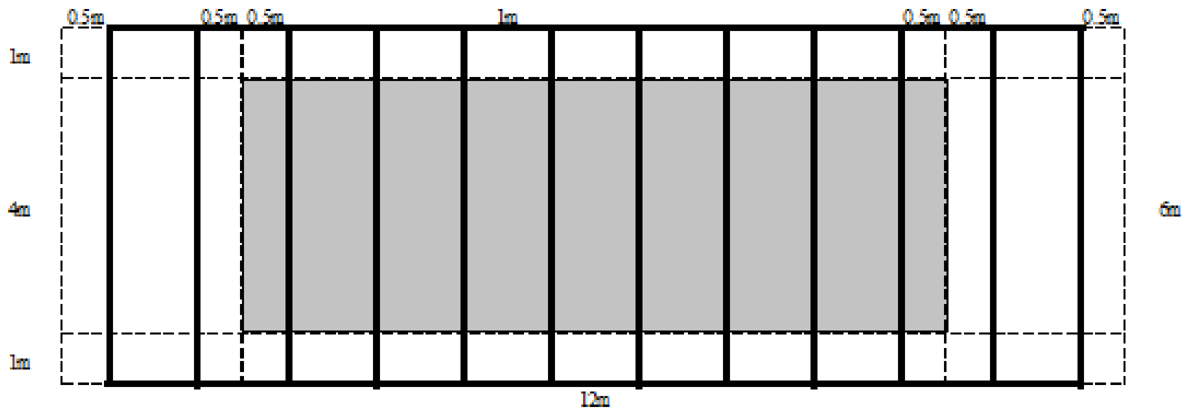


Figure 2. Schematic diagram of the experimental plot.

were distributed in a randomized block design with four replicates, totaling 20 experimental plots. The plots had dimensions of 6.0 x 12.0 m, with 72.0 m^2 of total area. The evaluated area corresponded to 32 m^2 (4.0 x 8.0 m), disregarding 1.0 m on each side along the width of the evaluated area and 1.4 m along the length of the plot (Figure 2). Gypsum application was performed by broadcast on soil surface, without incorporation. After treatments applying, the experimental area was subjected to irrigation for 90 days, in order to maintain the soil at field capacity and solubilize the gypsum.

Irrigation depths of 25 mm were weekly applied and, combined with the rainfalls, totaling 322.7 mm. This amount of water was calculated to solubilize the highest dose of mineral gypsum (8 Mg ha^{-1}), considering its solubility as approximately 2.5 g L^{-1} (Ramos et al., 2006).

Effect of gypsum on the exchangeable Ca, exchangeable Al and $S\text{-}SO_4^{2-}$ contents in the soil was evaluated at 0, 15, 64 and 90 days after its application. Five individual samples were collected in the tips and in the center of two diagonals drawn in the evaluated area of the experiment, in the layers of 0.0-0.2, 0.2-0.4 and 0.4-0.6 m. Soil pH in water and $CaCl_2$ also was evaluated.

Soil pH was determined in a proportion, 1:2.5 (solo : water). In 10 mL of soil were added 25 mL of water or 25 mL of $CaCl_2$ 0.01 mol L^{-1}. The sample was shaken and then rested for one hour. Soil pH was measured in potentiometer (Digimed® DM-22) (Donagema et al., 2011).

Exchangeable Ca and Al were extracted with KCl 1 mol L^{-1} from 10 mL soil sample after shaking for 15 min and overnight decantation. Exchangeable Al was determined through titration of a aliquot of 25 mL of the supernatant with NaOH 0.025 mol L^{-1} and 3 drops of bromothymol blue as indicator, and exchangeable Ca was dosed through atomic absorption spectrophotometry (PerkinElmer® AAnalyst 200) using half of the total volume with $SrCl_2$ to control readings interferences (Donagema et al., 2011).

Soil $S\text{-}SO_4^{2-}$ was extracted from 10 mL of soil sample using 25 mL of $Ca(H_2PO_4)_2$ solution containing 500 mg L^{-1} of P and $CaCl_2$ 0.01 mol L^{-1}. After extraction, $S\text{-}SO_4^{2-}$ was dosed by turbidimetry (Biospectro® SP-22) based on the optical density of the solution (420 nm) after addition of 500 mg of $BaCl_2.2H_2O$ (Alvarez et al., 2001). From 0 to 15 days after gypsum application, Al-compartments were evaluated in the treatments under the application of 0, 4 and 8 Mg ha^{-1} of gypsum. These Al-compartments were determined using the selective dissolution of Al.

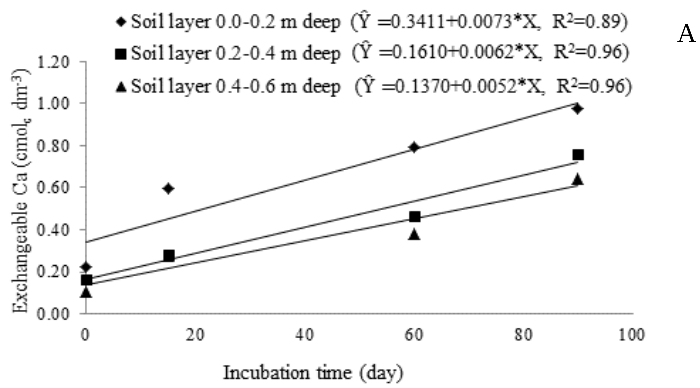
Al-crystalline was extracted with dithionite-citrate-bicarbonate solution (Mehra and Jackson, 1960). Al-amorphous compounds were extracted with solution of ammonium acid oxalate (Schwertmann, 1964). Al-organic matter was extracted with pyrophosphate solution (McKeague, 1967). After extraction, the Al was dosed through atomic absorption spectrophotometry (PerkinElmer® AAnalyst 200). Al-total was determined through titration with $ZnSO_4$ 0.0156 mol L^{-1} after sulfuric digestion (20 mL of H_2SO_4 diluted 1:1) for half hour in heater plate at 70°C (Donagema et al., 2011). Analysis of variance was performed in order to evaluate the effect of gypsum application, incubation time and the interaction between these factors in each layer individually. When significant qualitative effects were observed, the Scott-Knott test ($p<0.05$) was applied.

For significant quantitative effects, regression analysis ($p<0.05$) was used and the models were selected based on the significance of the regression coefficients and on the magnitude of the coefficient of determination.

RESULTS

Gypsum incubation for up to 90 days and the amount of water used in the irrigation, combined with the rainfall that occurred along the experiment, allowed the calcium and sulfate from the mineral gypsum applied on surface to move to soil deeper layers (Figure 3). The content of exchangeable Ca increased linearly with gypsum incubation time in all soil layers (Figure 3A) and $S\text{-}SO_4^{2-}$ content also increased over time, but stabilized at different levels according to the soil layer (Figure 3B).

In 90 days, the exchangeable Ca content was more than double of the initial content in the layer 0.4 to 0.6 m deep (Figure 3A). The curvilinear behavior $S\text{-}SO_4^{2-}$ content as a function of incubation time revealed migration of the anion, particularly in the layer 0 to 0.2 m deep. From about 59 days after gypsum application, the upper layer started to provide $S\text{-}SO_4^{2-}$ to the deeper soil layers (Figure 3B). Maintaining the curvilinear behavior $S\text{-}SO_4^{2-}$ content as a function of incubation time of the gypsum in the final layer showed that the $S\text{-}SO_4^{2-}$ continue moving in the soil profile. The increasing gypsum applications caused a high increment in the exchangeable Ca and $S\text{-}SO_4^{2-}$ contents in the layer of 0.0 to 0.2 m deep and a short increment in the layer 0.2 to 0.4 m deep (Figure 4). In the layer of 0.4-0.6 m deep,



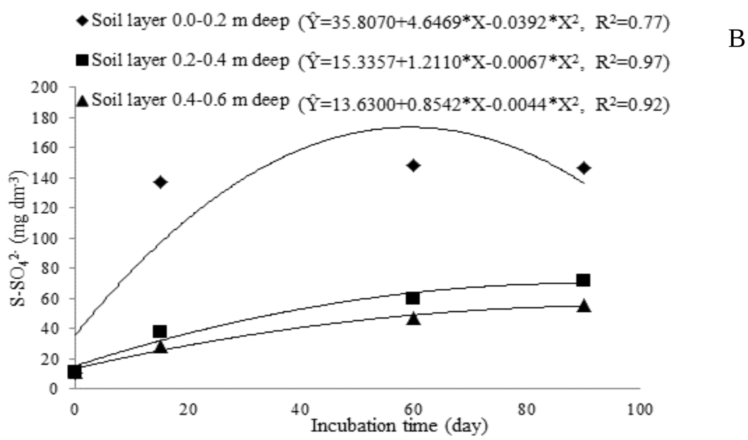


Figure 3. Exchangeable calcium (A) and sulfate (B) contents in the layers 0.0-0.2, 0.2-0.4 and 0.4-0.6 m deep in Hardsetting Ultisol as a function of the incubation time of mineral gypsum.

there was no effect of the applied amount of gypsum on the exchangeable Ca content (Figure 4A). The increment in the $S\text{-}SO_4^{2-}$ content by gypsum application stabilized with 8.79 Mg ha^{-1} in layer 0.2-0.4 m deep and 6.90 Mg ha^{-1} in layer 0.4-0.6 m deep (Figure 4B). Thus, based on the measurements of these two variables, it could be observed that gypsum moved vertically in the soil (Figure 3), but the applied amounts did not cause differences in this movement (Figure 4).

Increasing amounts of gypsum applied caused no effect on soil pH (Figure 5A), but soil pH (water) decreased with gypsum application time in all evaluated layers (Figure 5B). The decrease was curvilinear reaching a minimum value and then rise. The pH (water) decrease was greater in soil deeper layers, but this decrease in all layers only occurred until about 60 days after gypsum application (Figure 5B).

The pH (water) data in short periods of time are variable, especially when using gypsum or lime in the soil. To avoid this and to ascertain whether gypsum promotes or not change in soil pH, it was determined the pH in $CaCl_2$ 0.01 mol L^{-1} solution. Thus, it can be seen that neither time nor increasing amounts of applied gypsum changed soil pH (Figure 6). The amount of applied gypsum little modified exchangeable Al, showing effect only on layer 0.4 to 0.6 m deep (Figure 7A). The reduction in exchangeable Al content was 0.006 $cmol_c$ dm^{-3} for each Megagram of applied gypsum. The contents of exchangeable Al as a function of gypsum application time did not change in any soil layer, despite the increase in contents of exchangeable Ca and $S\text{-}SO_4^{2-}$ caused by application time of gypsum (Figure 7B).

In superficial layer, 15 days after gypsum application, the content of exchangeable Ca increased by approximately three times and the content of $S\text{-}SO_4^{2-}$ by approximately seven times, in relation to initial contents in the soil (Table 1 and Figure 3); however, the content of exchangeable Al did not change (Figure 7). Specifically in this soil layer, Al-organic matter was responsible for buffering the Al, because there was a significant decrease in the Al of this compartment (Table 2).

The reduction of Al-organic matter also occurred in the layer, 0.2 to 0.4 m deep (Table 3), where C contents remained high, as in the superficial layer (Table 1). Thus, this compartment, also in this layer, continued buffering the soil, because exchangeable Al content did not

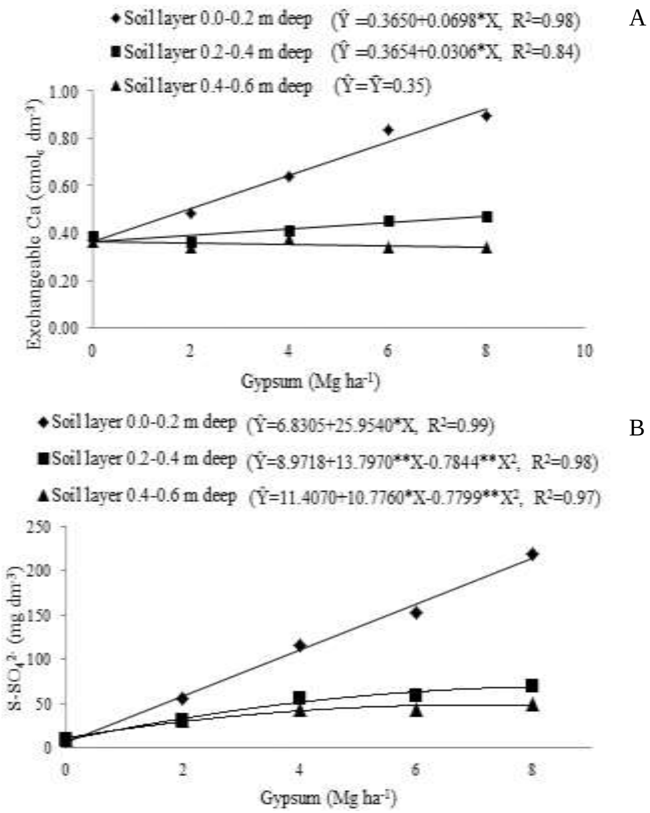


Figure 4. Exchangeable calcium (A) and sulfate (B) contents in the layers 0.0-0.2, 0.2-0.4 and 0.4-0.6 m deep in Hardsetting Ultisol as a function of the amount of mineral gypsum applied.

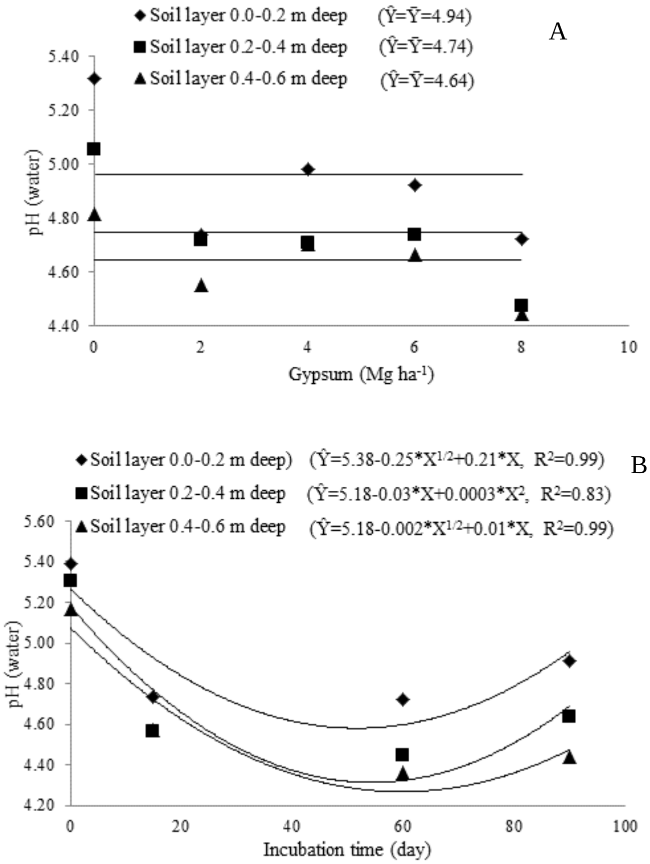


Figure 5. pH (water) in the layers 0.0-0.2, 0.2-0.4 and 0.4-0.6 m deep in Hardsetting Ultisol as a function of the amount of mineral gypsum applied (A) and as a function of the incubation time of mineral gypsum (B).

change with gypsum application (Figure 7).

In the subsequent layer, since C content decreased (Table 1), there was no significant reduction in Al-organic matter (Table 4). As soil depth increased, this compartment stopped being responsible for buffering the exchangeable Al. Gypsum application did not influence the Al-organic matter content in the superficial layer, although the use of 4 and 8 Mg ha^{-1} gypsum has reduced 0.56 and 1.08 g kg^{-1} the Al-organic matter content, respectively, as compared to treatment where gypsum was not applied (Table 2). Gypsum incubation time this layer was more effective in exchangeable Al buffering by Al-organic matter than the amount gypsum applied. In 0.2 to 0.4 m layer, Al-organic matter compartment increased with increment in the applied amounts of gypsum (Table 3). This compartment, besides buffering the soil can also complex this same Al in reactive less forms of organic matter.

Al-crystalline forms became responsible for the buffering of exchangeable Al as depth increased (Tables 2, 3 and 4). Al extracted using dithionite citrate bicarbonate (DCB) decreased significantly in the layer of 0.2-0.4 m deep as a function gypsum incubation time (Table 3) and in the layer 0.4-0.6 m deep as a function amount gypsum applied (Table 4). Al-crystalline forms in deeper layers controlled the buffering of exchangeable Al, not allowing gypsum to act on the reduction of this Al form in the soil (Figure 7).

Gypsum incubation time increased Al-crystalline content in the layer, 0.4-0.6 m deep (Table 4). However, in higher gypsum application rate, Al-crystalline was reduced. This Al compartment buffered soil exchangeable Al in high gypsum applied rate, but over time others Al-crystalline forms may have been reconstructed.

At the lowest gypsum applied dose, Al-crystalline and Al-amorphous content increased, and at higher gypsum doses they were reduced. The gypsum appropriate dose to correct the exchangeable Al was about 4 Mg ha^{-1}. So, all the exchangeable Al can have be neutralized and Al-crystalline and Al-amorphous increased. Excess exchangeable Ca provided by the high amount of gypsum applied can have moved others form of Al such as low crystallinity Al, for example. Buffering of this layer appears to have been performed by Al-crystalline and Al-amorphous, because the Al-organic matter in the deepest soil layer does not act in buffering.

Interaction between applied gypsum and incubation

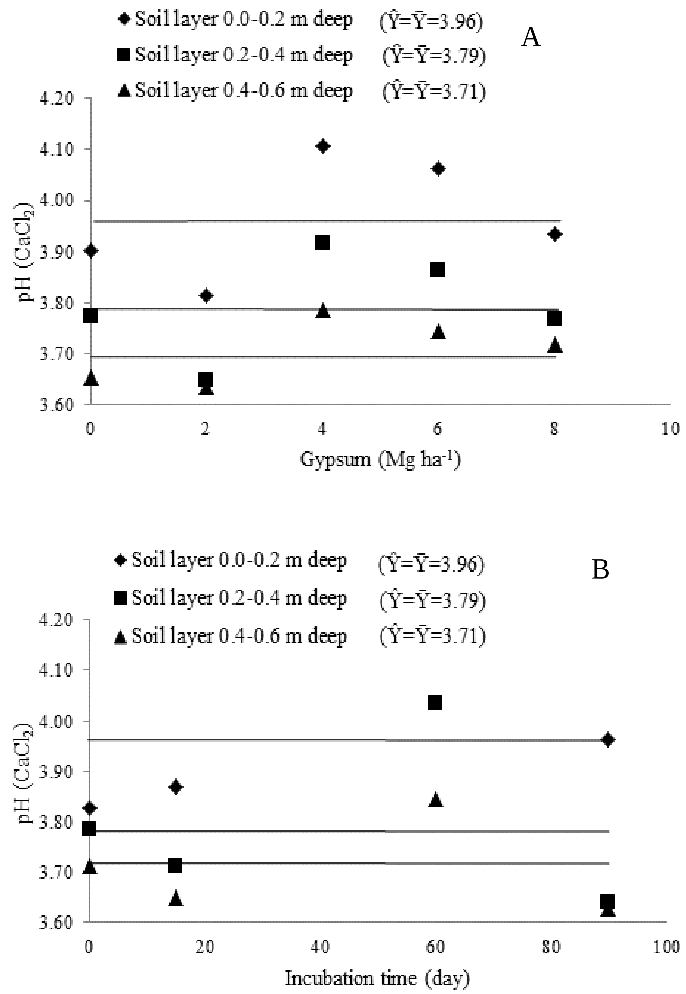


Figure 6. pH ($CaCl_2$) in the layers 0.0-0.2, 0.2-0.4 and 0.4-0.6 m deep in Hardsetting Ultisol as a function of the amount of mineral gypsum applied (A) and as a function of the incubation time of mineral gypsum (B).

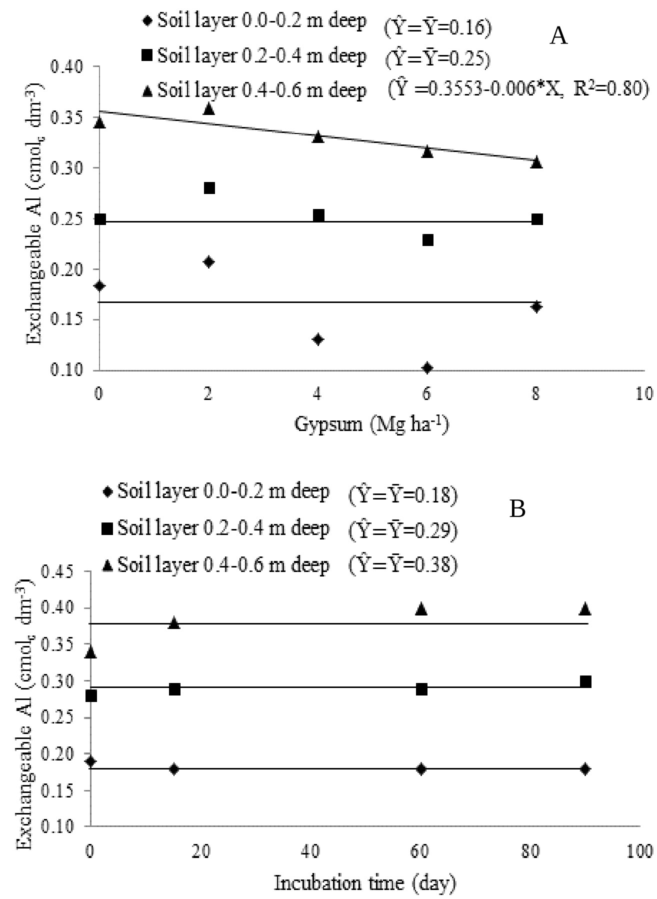


Figure 7. Exchangeable Al content in the layers 0.0-0.2, 0.2-0.4 and 0.4-0.6 m deep in Hardsetting Ultisol as a function of the amount of mineral gypsum applied (A) and as a function of the incubation time of mineral gypsum (B).

time was not statistically significant at any Al-compartment and soil layer. The main effects were independent. For example, treatment without gypsum application showed the same behavior as the treatments with application gypsum. Therefore, there were no other factors that may have interfered with the Al-compartments content in this study.

DISCUSSION

The capacity of gypsum to modify soil chemical characteristics can be evaluated through the increase in the exchangeable Ca and $S\text{-}SO_4^{2-}$ contents in cationic and anionic adsorption sites, respectively (Caires et al., 2011; Santos et al., 2013b), as observed in the present study (Figures 3 and 4), and also through its movement and action in deeper soil layers, promoting alterations in exchange complex in subsurface.

The slower displacement of $S\text{-}SO_4^{2-}$ and its later saturation can be attributed to some reasons: $S\text{-}SO_4^{2-}$ displaces, through mass action, the OH^- ions adsorbed onto the positively charged surface of oxides and clay minerals, occupying their spaces; $S\text{-}SO_4^{2-}$ in solution complexes exchangeable Al, forming insoluble $Al_2(SO_4)_3$; $S\text{-}SO_4^{2-}$ can also form ionic pairs with exchangeable Al, such as $AlSO_4^+$; there is also a preferential adsorption of $S\text{-}SO_4^{2-}$ by the exchangeable Al, in relation to the exchangeable Ca (Farina et al., 2000).

Reduction in soil pH (water) is commonly observed in study with gypsum application and incubation (Figure 5), however, this effect is due the action of soluble salts and increase of the electrolyte concentration that displace exchangeable Al to the soil solution. Al is hydrolyzed producing H^+ and lowering pH (water); therefore gypsum has no direct action on the soil pH (water) reduction (Ernani et al., 2001). According to Carvalho and Raij (1997), the pH measurement using solutions with defined concentrations provide the same ionic force in the pH

Table 1. Chemical and physical attributes in different layers of Hardsetting Ultisol in the experimental area.

Attribute	Layer (m)		
	0.0-0.2	0.2-0.4	0.4-0.6
pH (water)	5.39	5.30	5.17
pH ($CaCl_2$)	3.83	3.79	3.71
Ca^{2+} ($cmol_c$ dm^{-3})	0.36	0.26	0.17
Mg^{2+} ($cmol_c$ dm^{-3})	0.30	0.27	0.22
K^+ ($cmol_c$ dm^{-3})	0.06	0.03	0.01
Na^+ ($cmol_c$ dm^{-3})	0.02	0.01	0.01
Al^{3+} ($cmol_c$ dm^{-3})	0.19	0.28	0.36
(H + Al) ($cmol_c$ dm^{-3})	6.28	5.82	5.18
SO_4^{2-} (mg dm^{-3})	5.46	6.6	6.99
P (mg dm^{-3})	52.26	-	-
TOC (g kg^{-1})(1)	11.12	11.5	9.8
Total Al (g kg^{-1})(2)	24.71	23.37	28.05
Effective CEC ($cmol_c$ dm^{-3})(3)	0.93	0.85	0.77
Potential CEC ($cmol_c$ dm^{-3})(4)	7.02	6.39	5.59
V (%)(5)	10.54	8.92	7.33
m (%)(6)	20.43	32.94	46.75
Macroporosity (cm^3cm^{-3})	0.17	0.11	0.10
Microporosity (cm^3cm^{-3})	0.29	0.20	0.23
BD (kg dm^{-3})(7)	1.61	1.80	1.79
TP (cm^3cm^{-3})(8)	0.46	0.32	0.32
Sand (g kg^{-1})	776.4	760.4	728.4
Silt (g kg^{-1})	52.2	36.3	37.3
Clay (g kg^{-1})	171.4	203.3	234.3
Textural Class	Sandy clay loam	Sandy clay loam	Sandy clay loam

(1)Total organic carbon; (2)total aluminum; (3)effective cation exchange capacity; (4)potential cation exchange capacity; (5)base saturation; (6)aluminum saturation; (7)soil bulk density; (8)total porosity.

Table 2. Aluminum extracted content with acid ammonium oxalate (AAO), sodium pyrophosphate (pyrophosphate) and dithionite citrate bicarbonate (DCB) as a function of incubation time and amount of gypsum applied on the surface of a Hardsetting Ultisol in the 0.0-0.2 m layer, analysis of variance and coefficient of variation of the data.

Factor	AAO(1)		Mean	Pyrophosphate(2)		Mean	DCB(3)		Mean
	Time (days)			Time (days)			Time (days)		
	0	15		0	15		0	15	
Gypsum applied (Mg ha^{-1})					**g kg^{-1}**				
0	0.80	0.62	0.71	4.37	3.82	4.09	1.25	1.01	1.13
4	0.69	0.55	0.62	3.67	3.40	3.53	1.03	1.07	1.05
8	0.65	0.56	0.60	3.44	2.59	3.01	1.12	0.95	1.04
Mean	0.71	0.57		3.82A	3.27 B		1.13	1.01	
	F test			F test			F test		
Gypsum applied	1.30^{ns}			0.98^{ns}			1.37^{ns}		
Time	4.50^{ns}			5.37*			3.37^{ns}		
Gypsum applied x time	1.46^{ns}			0.23^{ns}			1.05^{ns}		
C.V. (%)	10.58			16.25			13.40		

(1)Al- Amorphous; (2)Al-organic matter; (3)Al-crystalline. equal letters, uppercase in the row and lowercase in the column, do not differ by Scott-Knott test (p<0.05).

Table 3. Aluminum extracted content with acid ammonium oxalate (AAO), sodium pyrophosphate (Pyrophosphate) and dithionite citrate bicarbonate (DCB) as a function of incubation time and amount of gypsum applied on the surface of a Hardsetting Ultisol in the 0.2-0.4 m layer, analysis of variance and coefficient of variation of the data.

Factor	AAO[(1)] Time (days)		Mean	Pyrophosphate[(2)] Time (days)		Mean	DCB[(3)] Time (days)		Mean
	0	15		0	15		0	15	
Gypsum applied (Mg ha^{-1})				g kg^{-1}					
0	0.65	0.56	0.61^{b}	4.25	4.22	4.24^{c}	1.46	1.34	1.40
4	0.75	0.74	0.75^{a}	6.37	5.52	5.95^{a}	1.58	1.27	1.43
8	0.67	0.68	0.68^{a}	5.07	4.76	4.92^{b}	1.53	1.20	1.37
Mean	0.69	0.66		5.23A	4.83^{B}		1.52^{A}	1.27^{B}	
	F test			F test			F test		
Gypsum applied	5.66*			97.67*			0.20^{ns}		
Time	0.84^{ns}			15.82*			10.54*		
Gypsum applied x time	0.76^{ns}			5.78^{ns}			0.80^{ns}		
C.V. (%)	10.44			42.41			11.60		

[(1)]Al- Amorphous; [(2)]Al-organic matter; [(3)]Al-Crystalline. Equal letters, uppercase in the row and lowercase in the column, do not differ by Scott-Knott test ($p<0.05$).

Table 4. Content of aluminum extracted with acid ammonium oxalate (AAO), sodium pyrophosphate (pyrophosphate) and dithionite citrate bicarbonate (DCB) as a function of incubation time and amount of gypsum applied on the surface of a Hardsetting Ultisol in the 0.4-0.6 m layer; analysis of variance and coefficient of variation of the data.

Factor	AAO[(1)] Time (days)		Mean	Pyrophosphate[(2)] Time (days)		Mean	DCB[(3)] Time (days)		Mean
	0	15		0	15		0	15	
Gypsum applied (Mg ha^{-1})				g kg^{-1}					
0	0.71	0.82	0.77^{c}	5.35	4.76	5.06	1.58	1.70	1.64^{b}
4	0.99	1.02	1.01^{a}	5.53	5.00	5.27	1.80	1.91	1.86^{a}
8	0.87	0.85	0.86^{b}	5.15	4.90	5.03	1.36	1.54	1.45^{c}
Mean	0.86	0.90		5.34	4.89		1.58^{B}	1.72^{A}	
	F test			F test			F test		
Gypsum applied	49.16*			0.28^{ns}			80.89*		
Time	4.17^{ns}			2.61^{ns}			27.19*		
Gypsum applied x time	3.64^{ns}			0.14^{ns}			0.58^{ns}		
C.V. (%)	4.85			11.72			33.41		

[(1)]Al- Amorphous; [(2)]Al-organic matter; [(3)]Al- Crystalline. Equal letters, uppercase in the row and lowercase in the column, do not differ by Scott-Knott test ($p<0.05$).

measurement solution, such as $CaCl_2$ 0.01 mol L^{-1} (Figure 6).

Reduction in exchangeable Al contents in subsurface is an expected effect when gypsum is applied (Li et al., 2010). This decrease is attributed to $S\text{-}SO_4^{2-}$, which, after forming ionic pair with exchangeable Al, removes it from the root zone, whether through in-solubilization [$Al_2(SO_4)_3$] or leaching ($AlSO_4^+$) (Saldanha et al., 2007).

Evaluating the effectiveness of gypsum application in soil focusing only on exchangeable Al determination may compromise the evaluation of the gypsum action and lead to misunderstandings in the interpretation of the results (Figure 7). Al dynamics is complex and its adsorption/desorption is related to the activity of different soil Al compartments (Coelho et al., 2010).

The main Al compartments responsible for the buffering of exchangeable Al are associated with the organic matter, cation exchange capacity and soil amorphous minerals (Coelho et al., 2010) and are susceptible to modifications caused by chemical alterations in the soil, such as gypsum application (Tables 2, 3 and 4).

These reactions probably occurred in this soil, both in surface and subsurface. However, the Al-organic matter and Al-crystalline prevented gypsum from reducing the exchangeable Al content (Tables 2, 3 and 4; Figure 7). According to Pedrotti et al. (2003), there are forms of reactive Al weakly associated with organic matter, reactive Al strongly associated with the organic fractions and non-reactive Al strongly complexed with the organic matter.

The increasing amounts of gypsum applied in this study caused increase in Al-amorphous compartment in subsurface (Tables 3 and 4). According to Takahashi et al. (2006), gypsum application reduces the solubility of exchangeable Al through the formation of Al-hydroxides and Al-sulfate minerals of low crystallinity. Álvarez et al. (2012) in experiment using limestone as soil conditioner, and Takahashi et al. (2006) using phosphogypsum, also observed increase in soil Al-amorphous contents.

Childs et al. (1983) reported that the increase in Al-amorphous in subsurface can be indicative of Al translocated from upper layers. Al leaching is one of the forms through which gypsum acts to remove high amounts of exchangeable Al from the plant root zone.

Conclusions

Gypsum application increased exchangeable calcium and sulfur contents in subsurface and did not reduce the exchangeable aluminum content. Soil pH (water) decreased with gypsum application time in all evaluated layers; however, there was no difference in soil pH ($CaCl_2$). Al-organic matter in the surface layer decreased along incubation time and gypsum application. Al-amorphous in subsurface layers increased with the increased amounts of gypsum. Al-crystalline decreased as soil depth increased. The buffering of exchangeable aluminum in surface layers was performed by Al-organic matter and, in subsurface, by Al-crystalline.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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Full Length Research Paper

Soil pH, available P of an ultisol and castor performance as influenced by contrasting tillage methods and wood ash

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The effect of tillage methods and rates of wood ash on soil chemical properties and castor bean plant performance was studied in field trial at Abakaliki in three planting seasons. The experiment was a split plot in randomized complete block design with three tillage methods (mound, ridge, flat) and four rates of wood ash (0, 2t, 4 and 6 tha^{-1}) replicated three times. Crop start version 7.2 was used to analyze data collected and mean separation was done using least significant difference (LSD) at 5% alpha level. The results of soil pH and available P showed that tillage method (TM) increased the values of the nutrients in 2nd year, but decreased in the 3rd year planting. The values of these parameters observed in Ridge method was found to be higher when compared to the values of Mound and Flat except for the result of available P in 1st and 3rd year planting periods. The wood ash (WA) amendment was found to change the soil from slightly acidic in 1st year to alkaline in 2nd year to slightly acidic in 3rd year. The control soil remained acidic throughout the three years of study. The available P obtained from Rd6 consistently gave the highest values among the TM and rates of WA. Tillage methods had no effect on leaf area index (LAI) at 50 days after planting (DAP) and 100 DAP in 1st and 2nd year planting periods, but had significant effect on the parameters in 3rd year planting season. Flat showed highest plant height in 1st and 2nd years but decreased in the 3rd year. While the least value in plant height for the 3 years' of study was recorded in Mound. The findings from this study has clearly shown that soil application of wood ash and tillage practices has the potential to cause positive and useful changes in the fertility and productivity status of the soil by improving the soil properties and yield component of castor.

Key words: Ash, available P, castor plant, leaf area, plant height, soil reaction, tillage.

INTRODUCTION

A stepwise increase in agricultural production across the globe is necessary in order to ensure the food supply for an increasing world population. As a result fallow periods are often reduced, shifting cultivation in the tropics leading to irreversible soil degradation and increased destruction of remaining natural forest due to cultivation of new area after slash and burn (Sanders et al, 1996; Woodruff, 2009). In most tropical environment, sustainable agriculture faces large constraints due to low nutrient content and accelerated mineralization of soil organic matter as a result of temperature and rainfall (Nweke, 2015). Soil fertility decline can as well occur through leaching, soil erosion and crop harvesting (Donova and Cassey, 1998). This trend that is fertility decline may be continuously experienced in tropical soil like Nigeria, unless the soil fertility status are replenished through the organic wastes, mineral fertilizer or through crop residues or rebuilt more comprehensively through traditional fallow systems that allow restoration of soil nutrients and reconstruction of soil organic matter, though this is not fully in practice due to increasing demand for land as a result of population increase (Akanbi et al., 2010; Nweke and Nnabude, 2014). Attempt have been made to improve soil properties of tropical soils of Nigeria through soil management practices such as tillage and incorporation of organic wastes, though the effectiveness of these wastes depend on the soil characteristic on which the waste will be applied.

Wood ash when used in agricultural soils has the potential to counteract the natural loss and loss of nutrients from crop harvesting. Its activities have been found to improve soil characteristics and crop performance. Agricultural fields need to be maintained as near as possible to neutral pH during cultivation and manure amendments applied to the top soil for immediate effect over short and long term periods. Wood ash has this capability as it has good acid neutralizing capacity and ability to supply the soil with basic cations; an ideal for tropical soils that are highly weathered and often classified as acidic or leached soils. Wood ash according to Eriksson (1998) contains in addition various concentrations of readily soluble neutral salts, such as sulphate and chlorides of Na and K. All these combined will create positive impact on the soil productivity and crop performance. Decreased acidity and increased base saturation and microbial activity have also been reported following wood ash application on agricultural soils (Bramryd and Fransman, 1995; Eriksson, 1998).

Soil structural modification through tillage is aimed at optimizing soil condition for seed germination seedling emergence and growth. Hence any good tillage method should therefore provide soil tilt, improve soil water infiltration and retention, reduce weed competition, minimize soil erosion, control infestation of pests, and encourage biological activities of soil micro-organism and recycle soil organic matter. Soil chemical indicators such as soil pH, available P, organic matter (OM), total nitrogen (TN), organic carbon (OC) etc are influenced by soil management practices such as tillage, organic waste application and cropping. In many ecological zones and on different soil types, crop response to tillage and indeed the economic viability of tillage systems are still subject of investigation (Aluko and Lasisi, 2009; Agbede, 2010). Thus the essence of this study was to evaluate the effect of contrasting tillage methods and wood ash on soil pH, available P and castor bean plant performance.

MATERIALS AND METHODS

Location of experiment

This study was carried out in three years cropping seasons at Teaching and Research Farm of Faculty of Agriculture and National Resources Management (FARM), Ebonyi State University, Abakaliki. The area of the study is located within latitude 06^o19^1N and Longitude 08^o06^1E of the southeast in the derived savannah agro-ecological zone of Nigeria. The rainfall distribution is bimodal with wet season from April to July and peak in June and September to November. It has an annual rainfall range of 1700 to 1800 mm. The temperature of the area ranges from 27 to 31°C. The relative humidity of the study area is between 60 and 80%. The soil is Ultisol and classified as Typic Haplustult by FDALR (1985).

Land preparation and treatment application

A land area measuring 41 m × 15 m (0.0615 ha) was mapped out and used for the study. The experimental site was cleared of the natural vegetation using cutlass and the debris removed. Tillage operation was done manually using hoe. The treatments are mound (Md), ridge (Rd) and flat (Ft), wood ash of different levels 0, 2, 4 and 6 t/ha was spread uniformly on the soil surface and buried in their respective plots immediately after cultivation. The details of treatments used are as follows:

1. Mound without wood ash (Md0)
2. Ridge without wood ash (Rd0)
3. Flat without wood ash (Ft0)
4. Md + 2 t/ha of wood ash (Md2)
5. Md + 4 t/ha of wood ash (Md4)
6. Md + 6t/ha of wood ash (Md6)
7. Rd + 2t/ha of wood ash (Rd2)
8. Rd + 4t/ha of wood ash (Rd4)
9. Rd + 6t/ha of wood ash (Rd6)
10. Ft + 2t/ha of wood ash (Ft2)
11. Ft + 4t/ha of wood ash (Ft4)
12. Ft + 6t/ha of wood ash (Ft6)

Two castor seeds per hole were planted at a spacing of 0.9 m between rows and 0.45 m within rows at a depth of 8 cm. There was basal application of NPK fertilizer to all plots two weeks after plant. The seedlings were thinned down to one plant per stand two weeks after germination. Weeding was done manually with hoe at 3-week intervals till harvest. The same procedure was repeated in

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the second and third year of the experiment but without application of wood ash in the third year to test the residual effect.

Experimental design

The total land area used for the study was 41 m × 15 m (0.0615 ha). The experiment was laid out as split plot in a randomized complete block design (RCBD), with 12 treatments replicated 3 times to give a total of 36 plots each plot measuring 3 m × 4 m (12 m^2). A plot was separated by 0.5 m alley and each replicate was 1m apart. Four (4) rates of wood ash viz., control (0t/ha); wood ash (WA) at the rate of 2 t/ha equivalent to 2.4 kg/plot, WA at 4t/ha equivalent to 4.8kg/plot and WA at 6t/ha equivalent to 7.2 kg/plot were used for the study. Each treatment was replicated 3 times along with the three tillage methods (mound, ridge and flat) used for the study:

Md0 = Mound without wood ash
Rd0 = Ridge without wood ash
Ft0 = Flat without wood ash
Md = Mound
Rd = Ridge
Ft = Flat

Soil sample collection

Auger soil samples were randomly taken from ten (10) observational points in the experimental area at the depth of 0 to 20 cm prior to planting. The Auger soil samples were mixed thoroughly to form a composite soil sample and used for pre-planting soil analysis. Also the wood ash treatment used was analyzed for determination of its nutrient values. At the end of each cropping season that is after crop harvest auger soil samples were collected from three observational points in each plot, the soil samples were air dried, sieved and used for chemical analysis.

Laboratory methods

Chemical properties

The soil sample collected for chemical analysis was air dried and sieved with 2 mm sieve and used for chemical properties determination.

Soil pH

The soil pH was measured in extract of soil solution in water at ratio of 1:2.5. After stirring for 30 min, the pH value was read using glass electrode pH meter.

Available phosphorous

This was determined by the procedure described by Bray and Kurtz (1945), Bray II method. The available phosphorous was read off from the standard curve after obtaining the optical density from colorimeter.

Agronomic parameters

The fertility status and productivity of any soil environment is physically observed or monitored and directly measured or quantified by measuring the agronomic parameters or properties of a crop growing on the soil. The measurement of which ranges from seed germination test to crop yield or seed yield depending on the desired parameter to be measured. For this particular study the following agronomic parameters were studied and measured.

Leaf area index (LAI)

Ten plants from each plot were randomly sampled and the LAI for each sampled plant was calculated as length × width × 0.75 summed over all leaves and divided by land area per plant.

Plant growth (m)

Ten castor plants per plot were sampled for plant height. This was taken at the end of the study with a tape. The measurement was taken from the plant base to the tip of the tallest leaf.

Data analysis

The data generated were subjected to an analysis of variance test based on RCBD using Crop Stat software version of 7.0, while statistically significant difference among treatment means was estimated using the least significant difference (LSD < 0.05).

RESULTS

Chemical contents of the study site and ash before treatment application

The initial soil properties presented in Table 1 show that the soil is acidic and the available phosphorous (P) value was relatively high with a value of 17.20 $mgkg^{-1}$. The properties of wood ash before application show higher concentrations of nutrients in the ash (Table 2). The pH of the ash is strongly alkaline (11.60) and very high in available P (261.10 $mgkg^{-1}$). Thus the ash is relatively rich in the plant chemical elements.

Effect of tillage and wood ash on soil pH and available P

The effect of tillage methods (TM) in Table 3 showed that the result of soil pH tested increased in the 2nd year planting, but decreased in the 3rd year planting. The change in soil pH for the 3 years' study in mound was from moderately acidic (1st year) to neutral (2nd year) and acidic (3rd year). In Ridge the change was moderately acidic (1st year) near neutral (2nd year) to moderately acidic (3rd year). While soil pH in flat showed moderately acidic for all the years under study. The soil pH values in 1st and 2nd year planting results showed a variation of mound > ridge > flat, while the 3rd year presented a contrary result order of flat > ridge > mound. The result variation of 1st year planting, however, showed that the values of soil pH obtained from mound, ridge and flat were relatively alike. This also applies to the 2nd year values of mound and ridge. The soil pH was non-

Table 1. Initial soil parameters before treatment application.

Test parameter	Value
pH (H_2O)	5.5
Available phosphorous (P)	17.20 $mgkg^{-1}$

Table 2. Chemical composition of the wood ash before application.

Test parameter	Value
pH (H_2O)	11.60
Available phosphorous (P)	261.10 $mgkg^{-1}$

significant ($P < 0.05$) during the TM in all the 3 years of study.

For the available P, the TM showed statistical significant effect in 1st and 2nd year planting with non-significant effect in the residual year. The result obtained from mound method showed that the value of available P decreased in the 2nd year planting, but increased in the 3rd year planting period. Hence the nature of the result was 1st year > 3rd year > 2nd year planting periods. The result variation in ridge was 2nd > 1st > 3rd year planting period, indicating that the highest value of available P in ridge method was obtained from the 2nd year planting as against the 1st year planting in mound. For the case of flat method, the result variation showed that highest value of available P was obtained from the 2nd year, while the least value of available P was observed in the 1st planting. In comparison of the TM in reference to the years' under study, 1st year result presented a variation of mound > ridge > flat; 2nd year ridge > flat > mound, while 3rd year showed mound > flat > ridge. The lowest value of available P among the TM in reference to the years under study was observed in flat in the 1st year planting period.

The effect of the wood ash result presented in Table 3 showed statistical significant difference among the rates of WA applied for the two tested parameters (pH and available P) and for the three years studied. The pH of the soil changed from slightly acidic in 1st year to slightly alkaline in 2nd year to moderately acidic in the 3rd year planting period. However, the control soil remained acidic throughout the period under study. The rates of WA ash apply in all the TM studied showed inconsistence in values obtained, which simply signify that the values are independent of the rates of WA applied. The rates of WA on mound showed that in 1st year planting, Md4 gave higher value of pH and the nature of result variation was Md4 > Md2 > Md6 > Md0. The Md2 and Md6 values were almost the same in fact; the 2nd year result showed that Md2 and Md6 yield the same value of soil pH; the 3rd year result showed a variation of Md6 > Md4 > Md2 > Md0. The rates of WA on ridge for the 1st year planting showed that the value of soil pH increased as the rates of WA applied increased. This scenario was equally true for the 3rd year result, but for the 2nd year result, the value of pH increased as the rates of WA increased, but decreased at Rd6.

Critical observation of the soil pH values for the 3 years study showed that the values of 2nd year > 1st year > 3rd year planting periods. The rates of WA on flat for the 1st year result showed that the values of soil pH increased as the rate of WA applied increased, but it decreased in Ft6. The 2nd and 3rd year results, however presented a perfect picture, that showed that the values of soil pH was dependent on the rate of WA applied because the values increased as the rate of WA applied increased. Hence the result order for the 2nd and 3rd year planting period was Ft0< Ft2< Ft4< Ft6. The 1st year result of available P in mound (Table 3) showed that Md4 had higher value compared to the other rates, Md4 > Md2 > Md6 > Md0. The 2nd year result showed a decrease in value among the rates relative to 1st and 3rd year values. From the residual year result, it was observed that the highest value of available P was obtained in Md2 and the least value from Md0.

For the 3 years study the lowest value of available P (14.8 $mgkg^{-1}$) was obtained from Md6 in the 2nd year planting period. The result of WA on Ridge for the 1st year planting indicated that the values of available P was dependent on the rates of WA applied as the values increased with an increasing rate of WA. The result of the 2nd and 3rd showed that the values of available P were independent of rates of WA applied. However, Rd6 in the 2nd year planting gave the highest available P values compared to the other rates the next in rank was Rd4. While in the 3rd year planting, Rd2 presented a highest value and next in rank was Rd6 among all the other rates. For 1st year result of WA on Flat, it was observed that Ft0 gave the highest value of available P and this value decreased as the rate of WA application increased, though an increased value was observed in Ft6 but not in comparison to the value obtained in Ft0. The 2nd year result presents a perfect order, indicating dependency of available P on the rates of WA applied. The value of available P increased with the attendant increase in the rates of WA, hence the order Ft6 > Ft4 > Ft2 > Ft0. The residual year result indicated a decrease in value of available P in Ft2, but later increased in response to the quantity of rates of WA applied.

The effect of tillage and wood ash on the two parameters was very effective, as it showed statistical significant different on the tested nutrients. In most results it was observed that the values obtained increased as the rate of WA application increased. The value recorded for available P showed that Ridge method and WA at the rate of 6 tha^{-1} (Rd_6) consistently gave the highest values among the tillage methods and rates of WA, though the value decreased in the residual year, but still greater than its value in Md6. The percentage decrease in the residual year relative to 2nd year planting

Table 3. Effect of tillage and wood ash on Soil pH and available P.

Treatment	1st Year		2nd Year		3rd Year	
	pH (H_2O)	P ($mgkg^{-1}$)	pH (H_2O)	P ($mgkg^{-1}$)	pH (H_2O)	P ($mgkg^{-1}$)
Md0	5.600	16.400	5.400	15.600	5.200	17.800
Md2	6.700	37.500	7.300	18.700	5.900	27.500
Md4	7.400	71.900	7.200	25.000	6.300	25.100
Md6	6.600	27.300	7.300	14.800	6.500	21.000
Mean	6.515	38.275	6.800	18.525	5.975	22.850
Rd0	5.800	14.800	5.700	14.800	5.400	18.600
Rd2	6.100	20.300	6.400	14.000	6.000	23.000
Rd4	6.800	25.000	7.400	36.700	6.100	22.000
Rd6	7.000	31.200	7.300	60.900	6.500	25.100
Mean	6.425	22.825	6.700	31.600	6.000	22.175
Ft0	5.700	16.600	5.500	13.200	5.500	16.600
Ft2	6.000	16.400	6.100	23.400	6.100	13.300
Ft4	7.000	14.000	6.500	27.300	6.400	22.600
Ft6	6.300	15.600	7.700	38.300	7.000	29.100
Mean	6.250	15.650	6.450	25.550	6.250	20.400
Tillage method	NS	10.99	NS	10.82	NS	NS
Wood ash	0.35	14.17	0.37	10.14	0.39	3.57
TM x WA	0.48	4.06	0.25	1.11	0.73	0.86

LSD0.05; Md0 = Mound without wood ash (WA); Md2 = Mound +2 t/ha WA; Md4 = Mound + 4 t/ha WA; Md6 = Mound + 6 t/ha WA; Rd0 = Ridge without WA ; Rd2 = Ridge +2 t/ha WA; Rd4 = Ridge + 4 t/ha WA; Rd6 = Ridge + 6 t/ha WA; Ft0 = Flat without WA; Ft2 = Flat + 2 t/ha WA; Ft4 = Flat + 4 t/ha WA; Ft6 = Flat + 6 t/ha WA.

was 142.635%. The available P content of the soil was greatly influenced by the application of wood ash as higher values were obtained in WA amended soils relative to the control soils

Effect of tillage and wood ash on leaf area index at 50 DAP and 100 DAP

The leaf area index (LAI) at 50 DAP and 100 DAP recorded in Table 4 showed that tillage methods had no effect on the leaf area index in 1st and 2nd years planting period and at 50 DAP in the 3rd year. But there was significant effect at 100 DAP at the 3rd year planting, the 1st year planting result of Mound showed that the value of LAI at 50 decreased as the year of planting increased, hence 1st year result > 2nd year result > 3rd year result. For the 3 years' of study the residual showed lowest value compared to 1st and 2nd year result. The percentage decrease in value of LAI at 50 DAP in residual year relative to 1st year result was 42.77%. The result of LAI at 100 DAP also indicated decreased value as the year of planting increased. The order of result variation was 1st year result > 2nd year result > 3rd year result. However, the result obtained from 1st and 2nd year planting were relatively the same as the percentage difference of the two results were merely 8.1%. But the LAI value decreased much in the residual to the tune of 47.16% relative to the 1st years planting result.

The result of the ridge also took the result line of the mound in the sense that for both 50 DAP and 100 DAP, the leaf area value showed 1st year result to be greater in value compared to 2nd and 3rd year values. The lowest value of LAI for 50 DAP and 100 DAP was observed in the residual year. The reduction in value for LAI at 50 and 100 DAP relative to the 1st year values were 45.1 and 34.92%, respectively; the result of LAI at 50 and 100 DAP obtained from flat method indicated decreased value as the year of planting increased, with the highest and lowest value observed in 1st and residual year result respectively. When the three tillage methods (mound, ridge, and flat) were compared, the LAI result at 50 DAP obtained in 1st, 2nd and 3rd year showed that mound was higher and the least was obtained from flat. The order of result variation for the 3 years' of study was mound > ridge > flat. The 100 DAP result present a contrary result order to 50 DAP as the result showed least value in ridge, hence the order mound > flat > ridge. The same order was observed in the 2nd year planting result, though the value of mound and flat are relatively the same as their percentage difference in value was merely 3.8%. The residual year (3rd) result indicated higher value in ridge and the least value in flat, variation of result showed order of ridge > mound > flat. The rates of wood ash were significant ($P<0.05$) for the leaf area index measured at 50 and 100 days after planting (DAP) for the 3 years planting period (Table 4).

The rates of WA application effect on mound for the

Table 4. Effect of tillage and rates of wood ash on leaf area index at 50 and 100 DAP.

Treatment	1st Year		2nd Year		3rd Year	
	50 DAP	100 DAP	50 DAP	100 DAP	50 DAP	100 DAP
Md0	7.655	21.608	7.606	21.558	3.756	10.553
Md2	9.997	27.565	9.740	27.390	6.072	13.366
Md4	14.313	29.799	14.264	29.749	8.086	16.673
Md6	12.309	27.668	12.259	27.620	7.421	15.755
Mean	11.069	26.660	10.967	26.579	6.334	14.087
Rd0	7.368	20.640	7.110	20.590	4.574	12.973
Rd2	10.186	17.063	10.136	17.041	5.463	17.644
Rd4	12.636	27.085	12.586	27.023	5.939	14.702
Rd6	13.009	27.689	12.959	27.514	7.707	14.859
Mean	10.799	23.119	10.698	23.042	5.921	15.045
Ft0	8.414	20.819	8.364	20.769	4.092	8.357
Ft2	13.704	28.148	13.653	28.098	5.703	10.630
Ft4	16.673	29.688	16..623	29.638	5.927	11.541
Ft6	15.554	27.707	15.504	27.658	7.804	12.994
Tillage method	NS	NS	NS	NS	NS	3.03
Wood ash	6.68	4.87	6.58	4.80	1.27	3.65
TM x WA	NS	8.20	NS	8.18	2.31	6.0
Mean	13.586	26.591	13.536	26.541	5.881	10.881

LSD0.05. Md0 = Mound without wood ash (WA); Md2 = Mound + 2 t/ha WA; Md4 = Mound + 4 t/ha WA; Md6 = Mound + 6 t/ha WA; Rd0 = Ridge without WA; Rd2 = Ridge + 2 t/ha WA; Rd4 = Ridge + 4 t/ha WA; Rd6 = Ridge + 6 t/ha WA; Ft0 = Flat without WA; Ft2 = Flat + 2 t/ha WA; Ft4 = Flat + 4 t/ha WA; Ft6 = Flat + 6 t/ha WA.

result of LAI at 50 DAP showed that for the 3 years' study, the result order for 1st, 2nd and 3rd year was Md4 > Md6 > Md2 > Md0. The result order was also true for LAI at 100 DAP, which indicated that for the 3 years' study the Md4 consistently gave the highest value of LAI at 50 DAP and 100 DAP. The WA application on ridge showed a contrary result order to that of mound as the highest value of LAI at 50 and 100 DAP was observed in Rd6 for the 3 years' of the study except the residual year result of 100 DAP. The result order for 1st, 2nd and 3rd result of LAI at 50 DAP was Rd6 > Rd4 > Rd2 > Rd0. The 100 DAP result did not follow any particular order the 1st year result indicated lower value in Rd2 and highest value in Rd6 among all the other rates.

The 2nd year result showed the same order of result like the 1st year because the order was Rd6 > Rd4 > Rd0 > Rd2. But then, the residual year (3rd year) result, the Rd2 which consistently recorded lowest value of LAI among all other rates of WA turned out to record the highest value of LAI at 100 DAP relative to the other rates. The value of this particular rate (Rd2) was 36.01 and 18.74% higher respectively to Rd0 and Rd6 which are rates that recorded the lowest and next in rank to Rd0 value. The application of WA on flat indicated a result order of Ft4 > Ft6 > Ft2 > Ft0. This order was true for 1st year and 2nd year result of LAI at 50 DAP. While that of 100 DAP showed an order of Ft4 > Ft2 > Ft6 > Ft0 for the 1st and 2nd year planting results. A contrary result order was observed in the residual year for the values of LAI at 50 and 100 DAP. The result variation for the two rates was Ft6 > Ft4 > Ft2 > Ft0.

The result presented in Table 4 showed that the tillage methods (TM) and wood ash was non- significant for leaf area index at 50 DAP in 1st and 2nd planting year, but significantly affected the leaf areas index at 100 DAP and 50 and 100 DAP of the 3rd year planting. There was a decrease in value as the planting period increased. The value of leaf area index obtained from the plots that received 4 tha $^{-1}$ (Md4, Rd4 and Ft4) WA was highest in 50 and 100 DAP among the values of the other rates in 1st and 2nd year planting periods while the rate that gave the highest LAI value at 50 and 100 DAP in the residual year (3rd) was the plots that received 6 tha^{-1}WA (Md6, Rd6 and Ft6). This indicates that 6 tha^{-1} rate have strong residual effect on the LAI more than the other rates. The 3rd year result in both 50 DAP and 100 DAP showed that LAI value was dependent on the quantity of WA applied as the result showed increased value as the rate of WA application increased.

The result of the leaf area index at 50 and 100 DAP generally show that the values decreased gradually from 1st to 2nd year planting and drastically at the 3rd year planting period. The influence of WA was much on the amended soils compared to the control soils as higher values were observed on the amended soil relative to the control soils.

Table 5. Effect of tillage and wood ash on plant height (m).

Treatment	1st Year	2nd Year	3rd Year
Md0	1.465	1.385	0.822
Md2	1.943	1.830	1.004
Md4	2.353	2.273	1.287
Md6	1.985	1.905	1.298
Mean	1.936	1.848	1.103
Rd0	1.584	1.504	1.049
Rd2	2.244	2.164	1.295
Rd4	2.454	2.374	1.345
Rd6	2.417	2.336	1.422
Mean	2.174	2.095	1.278
Ft0	1.897	1.817	0.965
Ft2	2.419	2.338	1.089
Ft4	2.610	2.530	1.274
Ft6	2.661	2.581	1.492
Mean	2.396	2.316	1.205
Tillage method	0.34	0.33	NS
Wood ash	0.30	0.29	0.24
TM x WA	0.44	0.43	0.46

LSD0.05. Md0 = Mound without wood ash (WA); Md2 = Mound + 2 t/ha WA; Md4 = Mound + 4 t/ha WA; Md6 = Mound + 6 t/ha WA; Rd0 = Ridge without WA ; Rd2 = Ridge +2 t/ha WA; Rd4 = Ridge + 4 t/ha WA; Rd6 = Ridge + 6 t/ha WA; Ft0 = Flat without WA; Ft2 = Flat + 2 t/ha WA; Ft4 = Flat + 4 t/ha WA; Ft6 = Flat + 6 t/ha WA.

Effect of tillage and wood ash on plant height (m)

The effect of tillage methods on plant height (PH) was significant ($P<0.05$) in 1st and 2nd year planting and non-significant in the 3rd year (Table 5). The result from mound indicated 1st year result > 2nd year result > 3rd year result, there was much decrease in value of PH of the residual year relative to the 1st year result of which the percentage decreased value was 43.03%. The result of PH obtained from ridge showed decrease in value as the planting year increased though the 1st and 2nd year value were relatively the same as the percentage difference of the two results was merely 7.8%. The 3rd year result showed decrease in value relative to both 1st and 2nd year result. The flat result showed a result order of 1st > 2nd > 3rd year. The percentage decrease in value of PH at 3rd year relative to the 1st year result was 49.71%. When the TM are compared, the 1st year planting result showed an order of flat > ridge > mound (Table 5). The decreased value in mound relative to the flat value was 19.20%. The 1st year result order was also observed in the 2nd year planting result, but the 3rd year result presented a contrary result order of ridge > flat > mound though the value of flat and mound did not vary much as the difference in their value was just 0.07 m.

The result of the rates of WA on the tillage methods significantly ($P<0.05$) affected the plant height for the 3 years studied. The rates of WA on mound showed a result order of Md4 > Md6 > Md2 > Md0 in 1st and 2nd year planting result, but the 3rd year result showed a contrary order of Md4 > Md6 > Md2 > Md0. The results just indicated that higher PH was observed in Md4 for 1st and 2nd year result, but in residual year higher value of PH was observed in Md6. The same scenario of WA result on mound was observed in ridge results, whereby Rd4 consistently recorded higher values of PH relative to other rates in 1st and 2nd year planting, while the 3rd year result indicated higher value of PH in Rd6 among all the other rates. The result order for ridge were Rd4 > Rd6 > Rd2 > Rd0 (1st and 2nd year result), and Rd6 > Rd4 > Rd2 > Rd0 (3rd year result). However, the result of WA application on flat presented a contrary order of result to that of mound and ridge in the sense that for 3 years' of study, the Ft6 rate consistently recorded the highest value of PH. The result order was Ft6 > Ft4 > Ft2 > Ft0 (Table 5).

Tillage method and wood ash effect on plant height showed statistical significant effect for the 3 years study. The values decreased as the year of planting increased. Also the values obtained were not dependent on the quantity of ash applied. Flat was observed to have recorded the highest PH in the 1st and 2nd year planting (Table 5), but decreased in the 3rd year where the Ridge recorded the highest plant height, while the least value in PH for the years under study was recorded in Mound. The wood ash application was found to influence the value of PH as higher values of PH were observed in ash amended soils compared to the control soils. The plots that received 4 tha^{-1} WA (Md4 and Rd4) gave the highest PH value in 1st and 2nd year planting periods while the plot that received 6 tha^{-1} (Md6, Rd6 and Ft6) rates of WA gave the highest PH value in 3rd year planting period indicating strong residual effect of 6 tha^{-1} on the PH compared to the other rates. The values decreased as the planting year increased. The data recorded equally showed that Flat and WA at the rate of 6 tha^{-1} (Ft6) consistently recorded the highest value of PH for the 3 years of study among all other rates studied on tillage methods. The rates of WA on Flat also showed the dependency of the PH value on the quantity of ash applied.

DISCUSSION

Properties of the soil and ash at beginning of the study

The soil analysis of the experimental site before the initiation of the study indicates that the pH of the soil was 5.5 which indicate acidity according to the ratings of USDA-SCS (1974) and Chude et al. (2005). This implies that the studied soil is well leached and strongly weathered. The available phosphorous (P) content of the soil was relatively rich with a value of 17.20$mgkg^{-1}$, the value observed is above the critical level for soils of south eastern, Nigeria according to the ratings of FMANR (1990). This high P observed in the studied soil may have arisen from P fertilization over the years in the study site, without regard to P mobility and nutrient reaction in the soil. Table 2 shows the nutrient composition of wood ash used as soil amendment. The nutrient content shows that the wood ash was very rich in available phosphorus (P) 261.10 $mgkg^{-1}$ and the pH of the ash were alkaline with a value of 11.60.

Soil chemical properties

The soil chemical parameters assessed indicated that tillage methods had effect on the chemical properties of the soil. Although after 3 years of study the parameters measured were found to be non- significant at $P<0.05$. The non- statistical significant differences observed among the tillage methods on the parameters studied and the cropping years observed may be that the 3 years study was not enough time for detecting changes in soil properties. Gomez et al. (2001) in their studies hypothesised that 5 years was enough time for detecting changes in soil properties. The result of soil pH and available P recorded showed that TM varied in their effect. The recorded value showed that mound gave higher values of soil pH and available P in 1st and 2nd years of planting and available P in 3rd year planting compared to ridge and flat. The flat showed least values in these two parameters.

This probable may be due to less soil inversion caused by manual hoeing in Flat compared with the mound and ridge. The pH of soil is important for a variety of reasons such as the solubility of aluminium which is toxic to many plants and organism, the weathering of minerals and the distribution of cation on the exchange complex. The potential differences in production between the three tillage methods (mound, ridge, flat) and differences in waste distribution in the soil also might have influenced the result of chemical parameters. Soil pH and nutrient availability are influenced by cropping systems and soil management practices like tillage methods, soil organic matter and biological activity. This scenario might have influenced greatly the result of the third year planting season.

The nature of the result of the tillage methods with regard to the chemical nutrients obtained may be linked to the environmental condition, type of soil and intensity of the tillage system that might have been done on the soil previously and those acting together with the type of crop species, soil properties and their complex interactions, according to Ishaq et al. (2002), might have influenced the nature of results obtained. Strudley et al. (2008) observed that the depth and intensity of tillage methods affect the soil chemical properties that affect plant growth and yield. This probable may be the reason why the results of the soil chemical properties obtained from mound and ridge differed much from that of Flat.

The WA effect showed that irrespective of the TM the ash was applied the pH of the soil changed from slightly acidic to alkaline in the 2nd year planting while the control soils remained acidic throughout the 3 years of the study.

The recorded values of pH when WA was applied in mound, ridge and flat were relatively alike. The available P content of the soil was found to be influenced by the application of WA. However, its value decreased irrespective of TM the WA was applied in 2nd year and 3rd year planting period. Though the decrease in value with regard to the aforementioned parameter in the 3rd year were inconsistent as the value of available P order was 1st year < 3rd year < 2nd year result. For the 3 years of the study the plots that received 6 tha^{-1} rate of WA had higher values of the tested parameters irrespective of the TM compared to the other rates studied in most cases except for WA on mound for the value of available P where plots that received 4 tha^{-1} showed higher value against 6 tha^{-1} rate for the 3 years study. The observed improvement in these tested parameters in amended soil could be attributed to the higher content of the nutrients in the WA applied as well as the synergistic relationship between the parameters and soil pH.

The higher pH values in amended soils relative to control could be attributed to the calcium supplied to the soil by the WA, and the level of soil available P might have being influenced by the changes in soil pH brought about by the application of WA. The solubility of mineral nutrients is greatly affected by soil pH. Phosphorus is never readily soluble in the soil but is most available in soil pH range that centred around 6.5. A soil pH range of approximately 6 to 7 promotes the most readily available chemical nutrients (Miller and Donahue, 1992; Tisdale et al., 1993). At pH below 6.0 there will be less nitrate production. Mbah and Oweremadu (2009) reported significant increase in the soil available P levels of the soils amended with organic wastes relative to the control plots. The liming effect of wood ash creates a more favourable pH in studies by Awodon et al. (2007), which showed increased soil nutrient content following plant derived ash application.

The effect of tillage and wood ash result showed that higher nutrient values were obtained more on WA treated plots compared to where WA were not applied. This observation was in line with the findings of Nweke et al. (2014) and Nnabude et al. (2015). Nweke et al. (2014) further reported that interaction between various levels of plant spacing and rates of poultry manure has positive effect on soil pH and ON, but non-significant for exchangeable bases, CEC and available P. For the parameters assessed it was observed that values obtained increased as the rate of WA application increased. The value recorded for available P showed that ridge method and WA at the rate of 6 tha^{-1} (Rd6) consistently gave the highest value among the TM and rates of WA though this value decreased in 3rd year planting and the percentage decrease relative to the 2nd year planting was 142.63%. Generally, the result showed that interaction between tillage methods and rates of WA can affect chemical properties of the soil.

Agronomic parameters of castor plant

The effect of tillage methods on the agronomic parameters of castor showed that the values of leaf area index (LAI) measured at two different dates decreased in the entire TM studied as the planting year increased. Higher values of LAI measured at 100 days after planting (DAP) was recorded in mound in 1st and 2nd year planting and next in rank was the value of Flat compared to the value of ridge. However the 3rd year result showed the ridge as the highest recorded value of LAI compared to mound and flat. The result of plant height (PH) indicated flat among the entire TM to have recorded the highest PH in the 1st and 2nd year planting season but decreased in the 3rd year where the ridge recorded the highest PH while the least value in PH for the 3 years of study was recorded in mound.

The seed yield result showed that the highest seed yield for the 3 years of study among the TM was recorded in mound and the least in ridge except the 3rd year result whereby the seed yield of ridge was higher than the flat value. Bessam and Marbet (2003) observed that conventional tillage promotes greater aeration of the soil which increases the breakdown of OM that releases a large quantity of nutrients to support plant growth. No wonder the much variation in the yield result of flat compared to the mound and ridge as rate of soil inversion during tillage is much in mound and ridge compared to flat.

The nature of the yield result obtained might be dependent on the type of test crop and TM studied because the best TM of one crop can adversely affect the productivity of another crop and soil properties. Hence indicating that crops may not always respond to a given tillage method in the same manner and degree. Kurshid et al. (2006) reported that among the crop production factors tillage contribute up to 20%, as it affects the sustainable use of soil resources through its influence on soil properties. Tillage system effects on yield according to Griffith et al. (1993) are highly dependent on upon soil type, drainage and climate. Singh et al. (2003) found out that the tillage method studied significantly influenced the grain yield of wheat over that obtained from zero tillage in the first and second year, however the effect of tillage in the third year were not significant. While Kombiok et al. (2005) assessed the effect of tillage systems (mounding, ridging, ploughing harrowing) and no-tillage (flat field) on cowpea growth and yield components under ferric luvisol in the northern guinea savannah zone of Ghana. They found that disc ploughing followed by disc harrowing resulted in the growth and yield of cowpea plant compared with that under no tillage (flat).

The WA effect on the agronomic parameters generally show that the values obtained decreased gradually from 1st to 2nd year planting and drastically at the 3rd year planting period. The values of LAI and PH recorded in 4 tha^{-1} WA gave the highest values of these parameters among the values obtained from the other rates in the 1st and 2nd year planting periods. While the rate that gave the highest value of these parameters in the 3rd year planting period was the plots that received 6 tha^{-1} WA showing strong residual effect on the assessed parameters compared to other rates of WA applied. The drastic reduction in the value of leaf area index in the 3rd year probable may be due to reduction in nutrient availability for the plant uptake. Significant effect in leaf area index following organic waste application has been reported in Nweke et al. (2013).

The recorded values of these parameters irrespective of the TM the ash was applied were relatively similar. The differences in values of the parameters tested could be attributed to the differences in plant nutrients in the rates of wood ash applied. Increases in plant height following addition of organic amendments have been reported by Nweke and Nsoanya (2013). The data recorded from the combined effect of TM and WA on the agronomic parameters of castor show that mound and WA at the rate of 4tha^{-1} consistently gave the highest PH values in 1st and 2nd year planting but decreased in the 3rd year planting. The highest value in pH was recorded in flat with 6 tha^{-1} rate of WA. The data recorded also show that TM and WA were much effective as the quantity of ash applied and planting period increased.

Conclusion

The effect of tillage methods and rates of wood ash on the tested parameters were significant. The values decreased as the cropping years increased. TM and WA effect were found to be effective on the assessed soil chemical parameters and higher nutrient values were more obtained in WA amended soils than in non-amended soils. Soil application of wood ash at the rates of 2, 4 and 6 tha^{-1} significantly increased castor growth relative to control plots. Also increasing the rate of wood ash application was found to have led to an increase in the growth and in the soil parameters. From the value recorded for the parameters tested in first and second year planting period, there was not much difference observed in 4 and 6 tha^{-1} rates of wood ash, but the residual year, the 3rd year planting period remarkable differences were observed in the results of the two rates (4 and 6 tha^{-1}), which shows that beyond 2 years, wood ash application at the rate of 6 tha^{-1} has strong residual effect on the parameters assessed. That is for 2 years cropping the optimum for wood ash application should be 4 tha^{-1} for cost effectiveness on the side of the farmer; but beyond 2 years the maximum should be 6 tha^{-1}. The values of the tested parameters varied among the tillage methods and planting periods observed. Tillage methods and wood ash effect was found to have significant effect on the parameters studied of which their values decreased as the cropping years increased. Wood ash can easily be sourced and it is cheap in the study area and its integration with tillage improved soil productivity and castor yield as was revealed in this study. The findings from this study has clearly shown that soil application of wood ash and tillage practices has the potential to cause positive and useful changes in the fertility and productivity status of the soil by improving the soil properties and growth of castor.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Socioeconomic determinants of hybrid maize adoption in Kenya

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Kenya has increasingly relied on modern agricultural technology to increase productivity since land extensification is no longer a feasible option to satisfy national food demands. Hybrid maize varieties have been one of the more successful technologies developed, responsible for dramatic yield increases in the developed world since World War II and more recently as an integral part of the Green Revolution. The purpose of this paper is to investigate the factors that affect the adoption of hybrid maize varieties in Kenya. A household survey was conducted to collect data on demographic and socioeconomic factors, as well as to elicit farmers' perceptions of the agronomic and consumption benefits of hybrid maize compared to open pollinated varieties. Using econometric (discrete choice) models, results showed that farmers' perceive that hybrid maize provides significant benefits in obtaining higher yields, but are less effective protecting against drought. Several other demographic and socioeconomic variables also had positive effects on hybrid maize adoption including access to modern farm equipment, distance to market, age, gender, education level and occupation of the household head. As Kenya and other African countries look to biotechnology as a means to increase productivity, the seed industry will need to continue finding ways to develop genetically modified maize to improve drought protection.

Key words: Hybrid maize, adoption, open pollinated variety, farmer's preference, Kenya.

INTRODUCTION

Maize is the most important staple food in Kenya, accounting for 65% of total staple food caloric intake and 36% of total food caloric intake (Ariga et al., 2010). However, domestic maize production is not keeping pace with the growth in national demand for maize. Imported maize has been increasingly filling the gaps left by insufficient domestic production, approaching an average of one million metric tonnes in an average year.

Land extensification and advanced agricultural technologies are two main paths to increase crop yields. With the supply of arable soil suitable for maize production exhausted by population pressure, Kenya will increasingly rely on modern agricultural technology to increase productivity since land extensification is no longer a feasible option to satisfy national food demands.

One of the most important methods to enhance maize

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productivity is to use improved maize varieties. In 1908, George H. Shull published a paper “The composition of a field of maize”, considered as the beginning of the exploitation of hybrid in maize breeding. By crossing inbred lines, hybrid maize varieties provide more stable and higher yield than randomly mated varieties, which are the open-pollinated varieties (OPV) (Crow, 1998). Transitioning from OPV to hybrid maize, however, requires a fundamental shift in farming. Producers become reliant on external seed sources and technological support. Agronomic conditions need to be properly maintained, which typically requires modern farming techniques compared to the traditional practices used on OPV. In the U.S., when hybrid maize became commercially available, some farmers were reluctant to adopt them initially. Demonstration plantings and field observations proved the worth of the hybrids. The demand for hybrid seed in 1935 in the Corn Belt exceeded production, and the hybrid seed industry developed rapidly (USDA, 1962) and has remained an integral part of the U.S. maize industry and its’ far reaching success in increasing maize yields.

In Kenya, and throughout the developing world, extending the use of hybrid maize varieties has been further challenged by a cultural attachment to OPV forged through generations of growing OPV varieties. The taste, color, texture and other consumption preferences are unique to local OPV and studies have documented the greater implicit value that households attach to OPV compared to hybrids. Such intrinsic value continues to make Kenyan farmers more reluctant to adopt improved maize varieties.

To increase hybrid maize adoption and its sustained use, it is critical to comprehend the factors determining adoption choice. Adoption studies investigate seek to identify factors significantly linked to the use and diffusion of new technology such as hybrid maize varieties and over the past few decades have become legion in the development literature (Kebede et al., 1990; Adesina and Zinnah, 1993; Adesina and Baidu-Forson, 1995; Chilot, 1996; Ouma et al., 2002; Doss 2003, 2006; Mignouna et al., 2010; Smale and Olwande, 2014). Although a variety of factors have been identified explaining patterns of initial adoption, long term use, and re-adoption of hybrid maize varieties, because of cultural, agronomic, natural resources, political, and socioeconomic differences, it is difficult to generalize those factors affecting significantly the adoption of new crop varieties, either within or between countries (Ouma et al., 2002; Wekesa et al., 2003; Mignouna et al., 2010; Smale and Olwande, 2014).

Findings from several adoption studies in Kenya highlight the transient nature of hybrid maize use and diffusion. In the Embu district of Kenya, Ouma et al. (2002) found that gender is the most influential factor determining hybrid maize use, given that men have a 55% higher probability than women of adopting improved maize varieties,. In addition to gender, access to labor, availability and application of organic fertilizers (manure), and on-site extension visits also have positive influence on the adoption of hybrid maize in Embu. However, other factors including access to credit use, education, age of household head, and farm size have no significant influence on decision-making.

Wekesa et al. (2003), in the coastal lowlands of Kenya, identified a rather different set of factors linked to hybrid maize adoption that suggest that producers place a large emphasis on the economic performance of hybrid maize. Liquidity- the availability of cash and short-term credit to purchase production inputs- was the most important factor for adoption of new maize production technologies. Household income (and presumably wealth) had a negative effect on adoption, as households with substantial sources of off-farm income were less likely to adopt new maize varieties than households engaged only in agriculture. Moreover, the higher cost of the hybrid maize varieties had a negative effect on its adoption, with farmers in coastal lowlands often opting to grow open pollinated varieties due to their lower cost. The poorly developed seed markets also had a negative effect on hybrid maize adoption, including limited hybrid seed supplies, the high cost of hybrid maize seeds, and the lack of extension and training needed required to successfully produce hybrid maize. A handful of other factors had a positive effect on hybrid maize adoption, including increased productivity (higher yields, larger cob sizes, more cobs per maize plant) and better grain filling than OPV maize.

A recent study made by Mignouna et al. (2010) on the adoption of *Imazapyr*-resistant maize (IRM), an improved maize variety that has strong resistance to *Striga* infestation in western Kenya, indicated that that age of the household head had a positive influence on IRM adoption. Mignouna et al. (2010) results run counter to most previous research on the adoption of not only hybrid maize, but of new agricultural technology in general (fertilizer, irrigation, animal traction, etc). The case of IRM stands out since older farmers have accumulated experiences from decades of maize cultivation, particularly *Striga* infestation, which made a significant difference between past technologies used for its control and the IRM variety. Farmers with more formal schooling were found to be more technically efficient than less formally schooled producers, indicating that farmers with more formal education respond willingly to the new technology and produce closer to the frontier of production possibilities.

Smale and Olwande (2014) investigated the long-run change in hybrid maize adoption on smallholder farms on Kenya given the substantial number of producers that grew hybrid maize for several years before returning back to OPV. Using the Tobit model it was detected that the gender of the household head had a significant effect on hybrid maize adoption. Female headship reduced the extent of hybrid seed use significantly compared to similar households led by a male patriarch. Unlike previous studies, neither education level of the household head nor labor size (family size) appears to influence the amount of hybrid seed planted among smallholder maize growers. Farm size (acreage) has a positive and significant relationship on the extent of hybrid maize seed demand, but its magnitude (explanatory power) was not large due to most of the households pursuing other production activities. Household wealth also had a highly significant effect on hybrid adoption.

Recent research by Schroeder et al. (2013) confirms findings from several previous adoption studies. The low hybrid maize adoption rates observed in their survey was explained by the lack of information and poor infrastructure found in the study area. There was an overall lack of awareness of newly released hybrid varieties, a lack of hybrid varieties adapted to the rather harsh agroecological conditions local marginal areas, a lack of confidence in the quality of some hybrid maize seeds, poor access to shop, low profitability due to high seed cost and high transportation costs, inadequate access to credit, and a generally low literacy level among heads of household.

Similar results have been found in other parts of Africa. Improved maize varieties adoption research in Southwest Nigeria found that age of the farmers had a negative effect on the adoption of improved maize varieties, whereas positive effects were identified for household size and education (Lawal et al., 2004). The negative effect of age on hybrid adoption is the more typical result as younger farmers appear more capable and willing to change and adopt technology innovations than older ones. Household size and education had a positive, significant effect on improved maize varieties adoption. The positive effect of household size and adoption were explained as larger households having a larger number of working members and will be more capable to withstand the increased level of risk and unintended consequences that are typically associated with the adopting technology innovations. Similarly, education provides an individual with a border formal intellectual horizon and can often enable farmers to better evaluate new information when deciding on the adoption of improved crop varieties.

The overall objective of this study is to determine the factors that significantly affect the adoption of improved maize varieties in Kenya. Specific objectives of this research are to: (1) Identify the preferences that Kenya maize producers have when selecting maize varieties; (2) Identify the preference differences between OPV maize adopters and hybrid maize adopters; (3) Quantify the valuations of maize characteristics across all farmers; estimate the weights of factors that influence the hybrid maize adoption; and (4) Identify factors that have a significant effect explaining the adoption and use of hybrid maize versus OPV maize.

The research presented in this paper is expected to contribute to the development of literature by providing a contemporary perspective on the status of hybrid use and choice among smallholder farmers. Although the study site is in Kenya, findings are expected to be of broader interest throughout East Africa and sub-Saharan Africa. Findings from this study will also be of interest to the Kenyan agribusiness community. Hybrid seed companies will have an updated adoption profile to assist in future breeding efforts to satisfy the needs and wants of Kenyan maize producers. Input providers can identify bottlenecks and other constraints found from the household interviews.

Maize in Kenya

Maize was first introduced in Kenya by Arab traders, and appeared in exhibitions at the first Agricultural Show in Nairobi in 1902 (Karanja, 1990). By 1903, maize covered about 20% of the total food crop area in Kenya (Meinertzhagen, 1957). In the early years, even though the crop was widely adopted by African farmers, commercial market outlets were weak, relegating maize to a subsistence crop. The first opportunity for Kenya farmers to increase maize production beyond subsistence levels came in 1942, when the colonial government enacted an increased production of crops by ordinance. This ordinance mobilized the farmers to increase production of all food crops, particularly maize, to feed troops and personnel during the Second World War (Karanja, 1996). In the aftermath of World War II, maize became more popular in Trans-Nzoia district; half of the large-scale farms in that area had begun to grew maize by 1964, the year first conventional hybrids were commercially released (Gerhart, 1975).The first hybrid maize seed H611, was commercially released in 1964 (Karanja, 1990). Between 1964 and 1990, a total of 18 hybrid maize varieties were released (Johnson, 1980; Karanja, 1996). Studies from CIMMYT (International Maize and Wheat Improvement Center) indicated that, based on seed sales, an estimated 62% of maize area was planted to hybrids in 1990 and 1996, and reach 68% by 2006 (Hassan et al., 2001; Langyintuo et al., 2008; López-Pereira and Morris, 1994). Now, most improved maize seed grown by farmers in Kenya is hybrid maize, as compared to a small amount of open pollinated varieties (OPV) maize.

Kenya's national maize production has doubled over the past fifty years (1963-2012), from around 1.5 million metric tons to slightly over 3.0 million metric tons (Figure 1). Those substantial gains in maize production and efforts to increase per-capita maize consumption were eroded by an even larger increase in Kenya's population, which more than doubled during that same time period (1963-2012) increased more than fivefold from 8.91 million in 1963 to 42.5 million in 2012 (World Bank 2016), Kenya's rapid population growth reduced per-capita maize production and stimulated staple food imports,

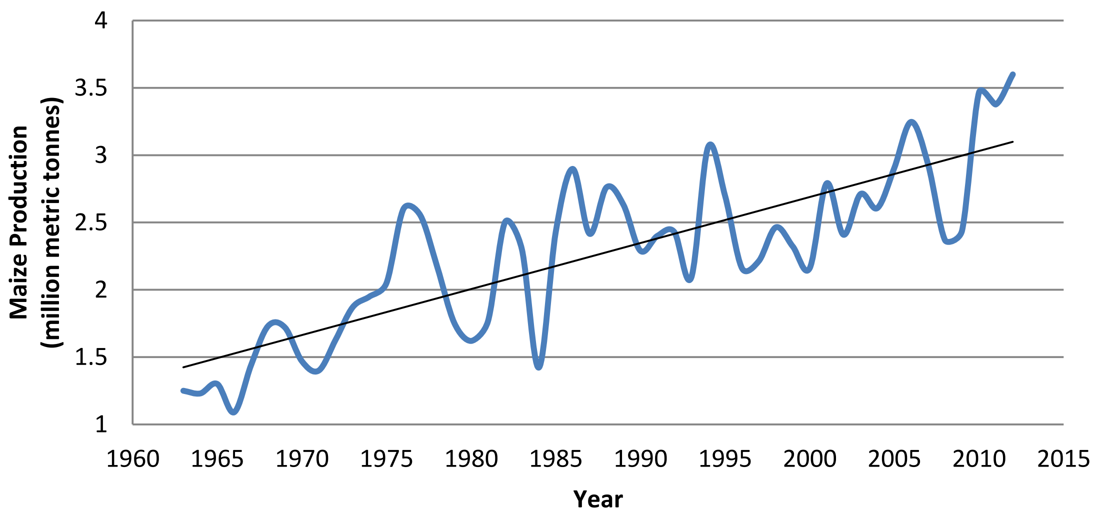

Figure 1. Maize production in Kenya for the last 50 years (1963~2012) (Source: FAO).

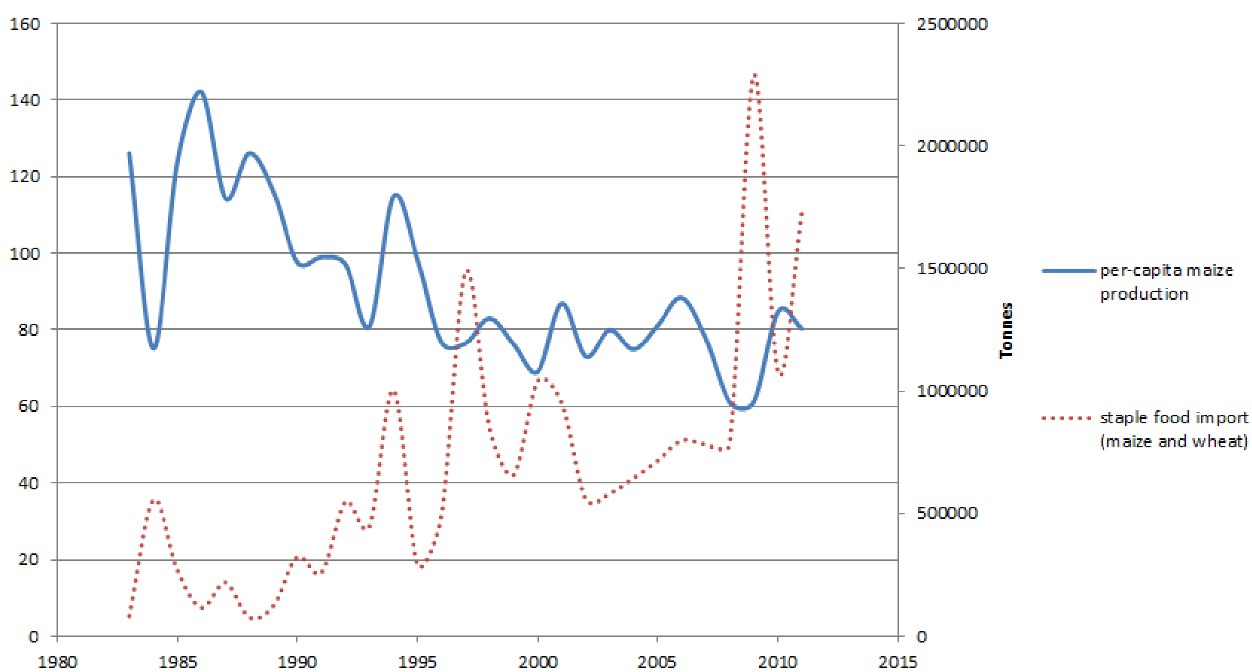

Figure 2. Per-capita maize production and staple food import for last 30 years (1983~2012) (Source: FAO and World Bank).

particularly over the past three decades (1983-2012) when maize productivity began to stagnate (Figure 2). It is hence necessary to revitalize agricultural productivity to satisfy the staple food needs of Kenya's growing population.

METHODS

Three steps were needed in order to determine which factors affect the adoption of improved maize varieties in Kenya. In the first step, a field survey instrument was developed and primary data was collected from on-farm site visits. In the second step, an empirical model was constructed using statistically rigorous econometric models. In the third step, significant variables were identified from the model results using statistical testing and compared to prior expectations and results from similar adoption studies.

Data

The surveys were conducted in eight different districts in Kenya across Kenya's two primary maize producing provinces, The Rift

Figure 3. Sample regions in Kenya.

Valley and Eastern (Figure 3). The Rift Valley Province surveys were obtained from the Trans Nzoiat, Kwanza, Wareng, and Eldoret districts, and the Eastern Province included the Yatta, Machakos, Maara, and Uasin Gishu. A total of 444 farmers were randomly selected based on each region's population density. This resulted in 199 farm surveys from the Eastern province and 245 farm surveys from the Rift Valley province.

A field survey questionnaire was developed to elicit maize farmers' preferences for hybrid maize versus OPV and to collect other data hypothesized as potentially linked to hybrid maize adoption. Four main parts were included in the field survey: (1) Socioeconomic status for head of household; (2) agronomic and production attributes of the farm; (3) farmers' preferences for hybrid versus OPV maize varieties; and (4) miscellaneous variables (extension, distance to roads, etc). Field survey questions are listed in Table 1.

Empirical model

Many studies of new technology adoption have used a logit model to identify adoption patterns and trends among a sample of producers (Schmidt and Strauss, 1975; Garcia et al., 1983; Kebede et al., 1989; Gabriel and Rosenthal, 1989; Yahanse et al., 1990; Polson and Spencer, 1991; Salalsya et al., 1996). The logit model can assess various factors that affect adoption of a given technology while providing predicted probabilities of new technology adoption. For example, the logit model can be used to

Table 1. Variable used in producer survey questionaire.

Variable	Definition	Response levels
Household head		
Age	Age of the household head.	Years
Gender	Gender of the household head.	Male = 1; Female = 0
Education	Education level of the household head.	No schooling = 0; Primary = 1; Secondary = 2; College = 3; University = 4
Occupation	Primary occupation of the household head.	Farmer = 1; Other = 0
Farm		
Household size	Number of persons in the household.	Integer number
Farm acreage	Total acreage of farm.	Acres
Preferences		
Early maturity	How early does the hybrid varieties mature compared to OPV?	Much earlier = -2; Earlier = -1; Same = 0; Later = 1; Much later = 2
Drought escape	How much drought escape does hybrid maize provide in below normal rainfall compared to OPV maize?	
Drought tolerance	How much drought tolerance does hybrid maize provide in years of below normal rainfall compared to OPV maize?	
Pest resistance	How resistant to pests is hybrid maize compared to OPV maize?	
Disease resistance	How resistant is hybrid maize to diseases compared to OPV maize?	Much worse = -2; Worse = -1; Same = 0
Yield potential	How well does the hybrid maize yield compared to OPV maize?	Better = 1; Much better = 2
Taste of green maize	How is the taste of green maize of hybrid maize compared to OPV maize?	
Taste of dry maize	How is the taste of dry maize of hybrid variety compared to OPV maize?	
Texture	How is the texture of maize of hybrid variety compared to OPV maize?	
Other		
Market distance	Distance to the nearest market.	Kilometers
Extension visits	Times extension officer visits in a typical year.	Integer number
Credit	Whether or not credit is used to purchase hybrid maize seed	Yes = 1; No = 0
Drought effect	Whether or not drought adversely affected maize crop	Yes = 1; No = 0
Preparation technique	Energy source for land preparation.	Human = 1; Oxen = 2; Machinery = 3

Kenyan farmers use both the metric and the English system.

indicate how the likelihood (probability) of a family adopting a particular technology changes according to the age of household head, keeping all other factors constant in the model. Profiles based on the likelihood of adoption provide a more realistic and useful metric since it generates information about the relative importance of each factor influencing adoption. Traditional econometric approaches test for statistical significance of individual factors but cannot readily assess their relative importance.

Logit model with binary response

Even though the binary response logit model has some limitations when applied to this type of research, it provides an initial basis for comparing among more elaborate discrete choice models considered as follows.

Liner Regression Model (LRM):

$$Y_i = \alpha + \sum_{i=1}^{k} \beta X_i + \varepsilon_i, \qquad \varepsilon_i \sim N(0, \sigma^2). \qquad (1)$$

Instead of modeling the linear relationship between the original dependent variable Y_i and the independent variables X_i, a discrete choice model analyzes the probability of a discrete event occurring, noted as $Y_i=1$, which can be explained by independent variables, X_i. Discrete choice models estimate a specific class of functions, probability functions, so that probabilities of the discrete values can be obtained. Many probability functions exist. One of the more suitable functions of this type is the logistic function, which assumes in particular that:

$$\pi_i = P(Y_i = 1|X_i) = F_{logit}\left(\alpha + \sum_{i=1}^{k} \beta X_i\right) = \frac{\exp\left(\alpha + \sum_{i=1}^{k} \beta X_i\right)}{1+\exp\left(\alpha + \sum_{i=1}^{k} \beta X_i\right)} \quad (2)$$

Where π_i represents the probability the Y_i=1 at a household *i*, P represents the probability that Y_i=1 given the vector of household adopt hybrid varieties, F_{logit} is the cumulative standard logistic distribution function, and β are the parameters from LRM. Hence, the probability that a household *does not* adopt hybrid maize can be expressed as:

$$1 - \pi_i = P(Y_i = 0|X_i) = \frac{1}{1+exp(\alpha+\sum_{i=1}^{k} \beta X_i)} \quad (3)$$

From Equations 2 and 3, the following is obtained:

$$Ln(\frac{\pi_i}{1-\pi_i}) = \alpha + \sum_{i=1}^{k} \beta X_i \quad (4)$$

Where the ratio $\frac{\pi_i}{1-\pi_i}$ is that Y=1, which corresponds to the ratio of the predictor in this linear logit response function.

Logit model with ordinal response

Due to the high expected adoption rate for hybrid maize varieties (>80%) in the study area the probability for $Y_i = 1$ is much higher than $Y_i = 0$ in the binary response logit model. It is thus more practical to assume farmers' adoption behavior has more than two levels. Under these more general conditions the polytomous logit model is more suitable than binary logit model since its structure can contain more than two discrete levels (Kutner et al., 2008). Farmers were separated into three groups based on their maize variety adoption behavior:

$$Y_i = \begin{cases} 1 & if\ household\ only\ adopted\ OPV\ variety\ (j = 1) \\ 2 & if\ household\ partly\ adopted\ hybrid\ variety\ (j = 2) \\ 3 & if\ the\ household\ only\ adopted\ hybrid\ variety\ (j = 3) \end{cases}$$

A polytomous logit model has two forms: An ordinal response model and a nominal response model. In the research, farmers' adoption response is from no hybrid maize at all to partly adopt hybrid maize, then to fully adopt hybrid maize. Therefore is an order among those response levels. If dependent variables are ordered rather than arbitrary, then the ordinal logit model should be used (Kutner et al., 2008). Which means the cumulative probability P (Y ≤ j) will instead the specific category probabilities P (Y = j) in the logit model. Then the proportional odds model was adopted:

$$P(Y_i \leq j|X_i) = \frac{exp\left(\alpha_j+\sum_{i=1}^{k} \beta X_i\right)}{1+exp(\alpha_j+\sum_{i=1}^{k} \beta X_i)} \quad (5)$$

According to Green (2002) and Kutner et al. (2008), one of the assumptions underlying ordinal logit regression is that the relationship between each pair of response categories is the same. In other words, ordinal logit regression assumes that the coefficients that describe the relationship between, in this case, group 2 (partly grew hybrid maize) versus group 1 (only grew OPV maize) of the response variables are the same as group 3 (only grew hybrid maize) versus group 2. The ordinal logit function for adoption level j can be expressed as:

$$Ln(\frac{P(Y_i \leq j|X_i)}{1-P(Y_i \leq j|X_i)}) = \alpha_j + \sum_{i=1}^{k} \beta X_i \quad (6)$$

The final logit regression model format as follows:

$$Ln\left(\frac{\pi_i}{1-\pi_i}\right) = \alpha_j + \sum X_i + \varepsilon \quad (7)$$

Where, $\pi_i = P(Y_i \leq j|X_i)$, the probability one household *i* response to adoption level j or lower; α_j = intercepts; X_i = independent variables (shows in the end of this chapter); ε = error term.

Parameter explanation for logit model

As discussed previously, the predictor of logit model is a natural logarithm for the ratio of odds that one event occurs ($\widehat{odds}1$), as a result, the interpretation of the estimated coefficient b_i would be the exponential odds ratio. For example, consider the value of the fitted logit response function for X= x' :

$$Ln(\widehat{odds}1) = \alpha + bx' \quad (8)$$

And for X = x' + 1:

$$Ln(\widehat{odds}2) = \alpha + b(x' + 1) \quad (9)$$

Therefore,

$$Ln(\widehat{odds}2) - Ln(\widehat{odds}1) = Ln\left(\frac{\widehat{odds}2}{\widehat{odds}1}\right) = b \quad (10)$$

Hence, the estimate odds ratio can be exhibited as:

$$\widehat{OR} = \frac{\widehat{odds}2}{\widehat{odds}1} = \exp(b) \quad (11)$$

Variable description

This variable that were included in the survey as well as their expected effect according to economic theory was discussed here. The survey variables were selected based on those included in previous research, as well as several new variables related to agronomic constraints (disease, pest, weather, etc) that have taken on new meaning with the emergence of genetically modified crops.

Demographic and socioeconomic variables

The age and gender of the household head (Age and Gender variables) were included in the survey and econometric model since the household head is the primary decision maker and previous research has identified age and gender as having a significant effect on variety choices (Table 2) (Smale et al., 2001; Stella et al., 2001; Ouma et al., 2002). The expected sign for age and gender variables is, however, difficult to predict *a priori*. Literature has found both positive and negative effects of age (Smale et al., 2001; Ouma et al., 2002).

The Education variable quantifies the education of the household head, the presumed decision maker. Education can be quantified in many different forms. In this research, only formal schooling is counted towards education; knowledge gained through actual farming is proxied by other variables such as age and access to agricultural extension. Formal education provides access to literacy, which has played a significant role in the adoption of agricultural technology (Doss, 2003; Lawal et al., 2004). Education often improves producers' ability to comprehend and internalize the innovations and subsequent impact of new technology on household welfare. Hence, the expected sign for this variable is

Table 2. List of independent variables and expected signs used in the econometric model.

	Variable	Expected sign
X_1	WP (weighted preference for maize varieties)	+
X_2	Age_middle $= \begin{cases} 1 & \text{for age household head over 40} \\ 0 & \text{otherwise} \end{cases}$	±
X_3	Age_older $= \begin{cases} 1 & \text{for age household head over 55} \\ 0 & \text{otherwise} \end{cases}$	±
X_4	Gender $= \begin{cases} 1 & \text{for male} \\ 0 & \text{for female} \end{cases}$	±
X_5	Edu_1 $= \begin{cases} 1 & \text{for education level of household head higher than primary} \\ 0 & \text{otherwise} \end{cases}$	+
X_6	Edu_2 $= \begin{cases} 1 & \text{for education level of household head higher than secondary} \\ 0 & \text{otherwise} \end{cases}$	+
X_7	Edu_3 $= \begin{cases} 1 & \text{for education level of household head higher than college} \\ 0 & \text{otherwise} \end{cases}$	+
X_8	Household size	+
X_9	Occupation	+
X_{10}	Farm acreage	+
X_{11}	Credit	+
X_{12}	Market distance	-
X_{13}	Extension visits	+
X_{14}	Drought effect	-
X_{15}	Preparation technique	+

positive. The relationship between education and choice may not be linear, that is, the effect of each level of education is not expected to be the same. For instance, the difference between three years of education in primary school is expected to have a lower effect on the likelihood of adopting improved technologies compared to three years of post-graduate work (Greene, 2002). To include the non-linear effects of higher levels of education, the education variable was placed in a category format so that each category would have an independent effect on variety choice, that is, act as a dummy variable.

The variable "Occupation" is included in the model to determine whether off-farm employment or other income sources for the household head has a significant effect on variety choice. If the household head has an occupation other than farming, their motivation to adopt hybrid variety may decrease. The expected sign for farming as primary occupation of the household head is hence positive (Kebede. et al., 1990; Smale et al., 2001; Wekesa et al., 2003).

The "Household size" variable is a measure of household labor availability for farming. Labor is an essential input for agricultural production. One feature of agricultural production is the uneven demand for labor, since conditions such as seasonal events, natural hazards, pest infestations, and crop variety may change the demand for labor. Farmers may choose not to adopt varieties that would require more intensive management practices and hence additional labor than the household can supply (Doss, 2003). A larger "household size" provides greater potential for labor supply, so its expected sign is positive.

The "farm acreage" and "preparation source" variables are proxy measures of the resource endowment and wealth of the household. Wealth can affect adoption decisions for several reasons, primarily because wealthy households have greater access to resources, more capacity to adopt a new variety, and greater ability to absorb financial risk. Larger farms have greater ability to absorb production risk. The expected sign for both "farm acreage" and "preparation source" are positive (Kebede et al., 1990; Smale and Olwander, 2012).

The "Credit" variable was included since adopting new technology such as hybrid varieties requires pre-planting expenditures that many households struggle to self-finance. This variable is difficult to measure correctly since it is difficult to distinguish farmers who choose not to use credit and the farmers who are not able to access credit. According to previous research, credit use usually has a significant positive effect on improved variety adoption (Smale et al., 2001; Wekesa et al., 2003).

The "Market distance" is included as a proxy measure of market access. Since the market is the place to purchase inputs and sell outputs, households with more convenient and less costly access to a market would have a greater potential level of adoption, holding constant all other factors. Hence, the expected sign for "Market distance" is negative (Salasya et al., 1998).

The "Extension visits" variable is a proxy-measure of access to information on new agricultural technologies. Extension service has been considered an important means of technology dissemination in agriculture, particularly in remote areas where communication is difficult. Farmers will likely not adopt new crop variety unless they are familiar with how the new technologies perform and how are produced. Theoretically, the number of extension officer visits should have a positive effect on new variety adoption, so the expected sign is positive (Salasya et al., 1998; Smale et al., 2001; Ouma et al., 2002; Ouma et al., 2006).

The two drought effect variables ("Drought escape" and "Drought tolerance") can be considered as proxy measures for producers concerns for drought and the stress that high heat and low soil moisture place on plant development. Adequate rainfall is a necessary factor for successful agricultural development since it enables higher productivity crops such as maize, so it was assumed that drought has more effect in the drier and less developed Eastern. The expected sign for the drought effect variables also depends on whether farmers perceive the hybrid maize variety as providing greater protection against drought than OPV. Hence, producers in the drier Eastern Province would have a positive sign if hybrids are drought tolerant, whereas Rift Valley producers would likely have the opposite sign since drought tolerant varieties are typically underperform in normal to above average rainfall conditions.

Preferences

The household surveys asked producers for their stated preferences comparing hybrid maize to OPV. Varietal preferences were measured in nine categories: Drought escape, drought tolerance, pest resistance, disease resistance, early maturity, yield potential, taste of green maize, taste of dry maize, and texture. Responses to each of the nine categories indicate how producers evaluate hybrid maize performance relative to OPV maize production and consumption attributes. As shown in Table 1, varietal preferences were partitioned into 5 levels, that is, Likert scales, from -2 to +2. If the value is positive, the farmer indicated that hybrid maize has better performance for this category, while a negative number indicates the farmer considered that OPV maize has better performance than hybrid maize.

An aggregate variable for producers' stated preferences was derived from the nine preference variables. Weights for each of the variables were used to develop a single overall aggregate measure of producers' stated preference for hybrid varieties. Attaching weights to each of the preference variables is necessary since farmers have individual attitudes on the importance of each maize characteristic. For example, some farmers may attach great importance to yield performance while others may place greater emphasis on taste when making decisions. Without weights, the nine maize characteristics would have been equally weighted across all farmers, an unrealistic assumption.

Weights for each of the nine characteristics were obtained from the producers during the survey. Producers ranked the importance of the characteristics using an ordinal ranking from 1 to 9. Producers were instructed to follow an ordinal ranking criteria among the nine categories, that is, number 1 indicates the most important (highest weighted) category and number 9 the least important (lowest weighted) category. Producers often placed multiple characteristics in the same level resulting in substantial number of "ties". There were also numerous instances where producers had no response to one or more of the variables. These three producers well document the two data collection issues that arose during the surveys, namely instances of "ties" among categories and categories for which producers did not respond.
In order to keep consistency, the ordinal rankings were adjusted according to the following pair of assumptions:

1. "Tie" ranking indicates that the two (or more) characteristics have the same weight for this farmer;
2. "N/A" and the blank response means the farmer would not consider this characteristic at all when they adopt maize varieties, thus they were considered as "0".

There is an alternative method to make the assumption 2: Consider the blank responses as the least important category for that farmer, which means fill the "N/A" responses with the largest ranking number plus one. The weights will be different, but analysis of this alternative indicated that the ranking and the logit model results were consistent with one another so the less cumbersome method, assuming zero weight, was chosen.
Based on the assumptions, generalizing the weight across all farmers requires the following three steps:

Step 1: Replace the "N/A" or "0" responses with positive infinity (a large positive number) to approximate a zero weight on the ordinal ranking. A new set of rankings is obtained that does not contain any missing/undefined attributes (Table 3).
Step 2: Generalize the ranking numbers. The formula for generalizing the ranking numbers is specified as:

$$\beta_{ij} = \frac{X_{ij}^{'}}{\sum X_{ij}} \tag{12}$$

Where: β_{ij} = generalized ranking number for household i response to characteristic j; $X_{ij}^{'}$ = ranking number for household i response to characteristic j from modified data. X_{ij} = ranking number for household i response to characteristic j from original data.
Step 3: Generalize the weight. The formula for generalizing the weights is specified as:

$$W_{ij} = \frac{\exp(-\beta_{ij} X_{ij}^{'})}{\sum \exp(-\beta_{ij} X_{ij}^{'})} \tag{13}$$

Where: W_{ij} = generalized weight for household i response to maize characteristic j; β_{ij} = generalized ranking number for household i response to maize characteristic j; $X_{ij}^{'}$ = ranking number for household i response to maize characteristic j from modified data.
Finally, the new variable weighted preference was formed:

$$WP_i = \sum W_{ij} P_{ij} \tag{14}$$

Where: WP_i = weighted preference for household i; W_{ij} = weight for household i response to maize characteristic j; P_{ij} = maize characteristic j for household i.

RESULTS AND DISSCUSSION

Summary statistics of data

Based on the different combinations of maize varieties grown on the surveyed farms, households were divided into three groups, corresponding to producers who grew: Only OPV maize, both OPV and hybrid maize, and only hybrid maize (Table 3). The average age of household head in the sample is 48.95 (Table 3). The mean value of the binary variable gender was 86%, meaning that 86% of the households were headed by males (Table 3). Hybrid maize adopters had on average a higher level of education, 1.6, compared to the OPV-only farmers, whose level averaged 1.29 (Table 3). Even though hybrid maize adopters had a higher level of education, the average education levels for all the three groups was 1.56, about midway between primary and secondary school (Table 3). Over half of the household heads had an occupation of farming, with an average of 59% across all three groups (Table 3). There was an increasing trend for the gender variable across the three groups, from 0.73 in the OPV-only group to 0.91 in the hybrid-only group (Table 3).

Household size was largest for the hybrid-only group, 6.29 persons, but there was no significant difference when compared to the other groups (Table 3). Producers who grew both varieties of maize had an average household size of 5.79 persons and the OPV-only group had an average size of 5.28 persons (Table 3).

The mean acreage for each group is 2.04 acres for OPV-only, 4.73 acres for both, and 6.20 acres for hybrid-only. Similarly, land preparation technique value was significantly larger for hybrid-only households (2.39) than

Table 3. Demographic and socioeconomic variables for different adoption groups.

Groups	OPV-only (Obs 41)		Grow-both (Obs 114)		Hybrid-only (Obs 289)		Total (Obs 444)		t-test for significant difference(P value)		
Variables	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**OPV-onlyversus Grow-both**	**OPV-only versus Hybrid-only**	**Grow-bothversus Hybrid-only**
Household head:											
Age	48.83	14.92	52.05	12.01	47.73	15.05	48.95	14.41	0.171	0.663	0.007
Gender	0.73	0.45	0.8	0.4	0.91	0.28	0.86	0.34	0.451	0.001	0.001
Education	1.29	0.64	1.53	0.77	1.6	0.85	1.56	0.82	0.086	0.024	0.404
Occupation	0.51	0.51	0.64	0.48	0.59	0.49	0.59	0.49	0.152	0.358	0.337
Farm:											
Household size	5.28	1.77	5.79	2.63	6.29	3.03	6.07	2.85	0.253	0.039	0.122
Farm acreage	2.04	1.78	4.73	10.25	6.2	12.06	5.44	11.1	0.103	0.028	0.251
Other:											
Credit	0	0	0.08	0.27	0.02	0.14	0.03	0.18	0.064	0.353	0.005
Market distance	4.82	4.64	4.28	4.78	6.8	8.56	5.97	7.52	0.534	0.148	0.003
Extension visits	5.2	9.5	5.67	10.39	2.99	7.07	3.87	8.33	0.802	0.077	0.003
Drought effect	0.95	0.22	0.9	0.3	0.57	0.5	0.69	0.46	0.282	<0.001	<0.001
Preparation technique	1.5	0.6	1.76	0.61	2.39	0.79	2.15	0.8	0.009	<0.001	<0.001

for households that grow-both and for OPV-only households (Table 3).

The data shows that very few households use credit, with an average of 3% across all groups (Table 3). The OPV-only group, as expected, did not use any credit (Table 3). On average, OPV-only and grow-both group are closer to market than the hybrid-only group (Table 3). The survey also shows that mean number of extension visits for the hybrid-only group (2.39) is much lower than for the Grow-both (5.67) and OPV-only (5.2) groups (Table 3). The negative influence for drought is much lower for the hybrid-only group (57%) than the other two groups, with the greatest concern among OPV-only (95%). The mean value of land preparation technique for grow hybrid maize group is 2.36, which indicates a majority of families using oxen for land preparation and a smaller proportion using machinery. The mean values for OPV-only and grow-both household are 1.50 and 1.76, with 0.60 and 0.61 standard deviations respectively, indicating that most families in those two groups use oxen and human for land preparation.

Hybrid variety performance

Hybrid varieties performed better, according to producers' subjective evaluation, in all of the categories except "Drought escape" (Table 4). Substantially greater performance was found in both the overall sample, as well as within each of the three producer groups. Moreover, there is a noticeable increasing trend across the three groups (going from left to right in Table 4) in nearly all (seven out of nine) of the categories, which confirms prior expectations that hybrid-only farmers believe hybrids perform much better than OPV (Table 4). In the subcategory preferences, the larger the absolute value, the larger the gap the household believed existed between hybrids and OPV (Table 4). The most significant gap is "yield potential" (1.48), the second largest is found within the "texture", while the smallest gap is within the "drought escape" variable (-0.10).

Weighted preference (WP) was calculated using Equation 14. After weighting, the preference is transformed into a continuous variable with a range from -2 to 2. The average WP for total sample is 0.87, which means in general, maize

Table 4. Subcategories preferences and weighted preference for different adoption groups.

Groups	OPV-only(Obs 41)		Grow-both(Obs 114)		Hybrid-only(Obs 289)		Total(Obs 444)	
Preferences	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
Drought escape	-0.07	1.08	-0.26	1.10	-0.04	1.19	-0.10	1.16
Drought tolerance	0.02	1.17	0.13	1.21	0.49	1.09	0.35	1.14
Pest resistance	0.05	0.96	0.26	1.01	0.70	0.92	0.53	0.98
Disease resistance	0.12	0.98	0.30	1.03	0.70	0.94	0.54	0.99
Early maturity	-0.02	1.23	0.40	1.05	0.48	1.09	0.41	1.10
Yield potential	0.95	0.94	1.36	0.76	1.61	0.54	1.48	0.68
Taste of green maize	0.22	0.97	0.11	1.12	0.69	1.06	0.50	1.10
Taste of dry maize	0.15	1.09	0.18	1.16	0.74	1.09	0.54	1.14
Texture	0.79	0.70	0.79	0.70	1.05	0.75	0.96	0.74
Weighted preference	0.32	0.63	0.61	0.67	1.05	0.57	0.87	0.66

Preferences were partitioned into 5 levels from -2 to 2. If the value is positive, a farmer indicated that hybrid maize has better performance for a subcategory.

Table 5. Generalized weights (average) and ranking for different groups households.

Groups	OPV-only(Obs 41)		Grow-both(Obs 114)		Hybrid-only(Obs 289)		Total(Obs 444)	
Characteristics	**Weight (%)**	**Ranking**	**Weight (%)**	**Ranking**	**Weight (%)**	**Ranking**	**Weight (%)**	**Ranking**
Yield potential	25.13	1	32.28	1	44.64	1	39.66	1
Early maturity	14.82	4	16.36	3	13.52	2	14.37	2
Drought escape	14.93	3	14.02	4	9.44	5	11.33	3
Drought resistance	17.86	2	16.63	2	7.27	6	10.66	4
Disease resistance	7.66	5	7.09	5	12.10	3	10.40	5
Pest resistance	7.06	6	6.76	6	10.21	4	9.03	6
Taste of green maize	5.76	7	3.14	7	1.49	7	2.31	7
Taste of dry maize	4.03	8	2.28	8	0.77	8	1.46	8
Texture	2.75	9	1.42	9	0.54	9	0.97	9

producing households consider hybrid maize performs slightly better than OPV maize (Table 4). The greater performance of hybrids is more apparent when compared across the three groups. The hybrid-only group has the most favorable preference of hybrids, with a weighted preference of 1.05, which is 40% larger than producers who grow-both OPV and hybrids, 0.61, and the OPV-only group, whose WP was 0.32 (Table 4).

Yield potential accounts for the largest weight for all three producer groups (Table 5). The importance of yield potential is most apparent within the hybrid-only group, where it accounts for almost 45% of the total weight (Table 5). The average weights for early maturity, drought escape, drought resistance, disease resistance and pest resistance are almost identical (a range from 9 to 14%). The least important characteristics of maize were those related to consumption: Taste of green maize, taste of dry maize, and the texture of the maize when made into *ugali*, a corn meal with the consistency of mashed potatoes that is the staple dish of Kenya. The ranking of these three consumption related characteristics is consistent across all three groups (Table 5). The lack of importance of maize as a consumption good is particularly noteworthy. The survey results indicate that households place more value on growing a maize variety with stronger agronomic performance rather than for its role as a staple food. This result suggest that rural households are more market oriented than in the past, perhaps signaling a long-term shift towards more commercialization in the maize sector. Moreover, the OPV-only group places a larger weight on the last three characteristics (11.54% total) than the Grow-both group (6.84% total) and hybrid-only group (2.8% total).

Model results

Maximum likelihood estimation results for the ordinal logit model were obtained using the SAS PROC Model statement. The logit model provides a modestly good fit to the data with a log likelihood value of -280 and nine out of seventeen variables statistically significant (P<0.05).

Table 6. The result of the model for factors affecting choosing maize varieties.

Variable	Coefficients	Standard Error	Pr > |z|	Odds ratio
Weighted preference	1.051	0.192	0.000***	2.859
Preparation technique	0.729	0.172	0.000***	2.073
Drought effect	-1.148	0.368	0.002***	0.317
Occupation	0.430	0.252	0.088*	1.538
Market distance	0.057	0.024	0.020**	1.058
Gender	0.650	0.324	0.045**	1.915
Age_middle	-0.553	0.312	0.076*	0.575
Age_older	0.352	0.280	0.208	
Edu_1	-0.475	0.489	0.332	
Edu_2	-0.040	0.260	0.879	
Edu_3	0.776	0.448	0.084*	2.172
Household size	0.041	0.045	0.364	
Farm acreage	0.026	0.020	0.199	
Credit	-0.306	0.566	0.589	
Extension visits	-0.010	0.013	0.421	
Intercept 2	-1.494	0.753	0.047*	
Intercept 1	0.666	0.747	0.373	
Log Likelihood	-280			
Obs	432			

This model is based on Ordinal logit model regression with dependent variable; * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. 12 observations were deleted due to missing values or exceptional survey response.

The odds ratio change is not as straight forward to interpret as the probability change, which is given by the coefficients estimated in linear probability model. However, according to Maddala (1983), dividing the logit coefficients by 4 gives an approximation of the linear probability coefficients.

The weighted preference (WP) is one of the most significant and influential variables in the model (Table 6). According to Maddala (1983), the WP coefficient of 1.051 indicates that, holding other conditions constant, a one-unit increase in WP increases, the probability for one household to reach a higher adoption level (that is, OPV-only to grow-both, or grow-both to hybrid-only) will increase by 26% (Table 6). The WP variable is a combination of nine preferences about maize characteristics and their associated weights. The weight of maize performance characteristics indicated that yield potential account for almost 40% of the total weight (Table 5), and yield potential is the most outstanding performance characteristic for hybrid varieties compared to OPV (Table 4). The results suggest, hence, that yield potential is highly influential in the maize variety selection process.

Land preparation technique is one of the two most significant variables (*P*<0.0001), along with WP, in the Logit model (Table 6). Significance of the land preparation variable implies that households who use oxen or tractor to prepare the farmland, rather than by manual means (hand-n-hoe), have a higher probability of adopting a hybrid. Since land preparation is a proxy to family wealth and resource holdings, the significance of land preparation also implies that richer households have a greater probability to have adopted hybrid maize varieties. The positive effect of wealth on hybrid adoption is consistent with the findings from Smale and Olwande (2014).

Drought effect was significant in the model (*P*<0.01; Table 6) with a negative effect on hybrid maize adoption. Climate has a significant impact on Kenyan maize production, which explains why hybrid maize adoption rate is lower in the area where drought is more prevalent. Household survey data shows found that hybrid maize adoption rate is 99% in Rift Valley Province and 80% in Eastern Province. These results suggest, therefore, that existing hybrid maize varieties marketed in the drought-prone areas have no significant yield advantage, compared to OPV maize, in drought prone years. With improved breeding for drought resistance, and holding all else constant in the model, hybrid maize adoption rate would be expected to increase. The statistical data confirmed this implication. The total sample mean value for drought tolerance is 0.35 and for drought escape is -0.1 (Table 4). This indicated on average, farmers considered current hybrid maize varieties performed slightly better than OPV on drought tolerance but perform worse by a substantially greater amount on drought escape.

Market distance is the only significant variable in the model whose effect (sign on the coefficient) was contrary to prior expectations (Table 6). The relationship between market distance and hybrid maize adoption is expected to be negative because closer market proximity should reduce cost and enable greater access to market information. The estimated coefficient of the Market distance variable is 0.056 can be explained as indicating that a one-mile increase in distance to market increases the probability of reaching a higher level of adoption by approximately 1.4% (Table 6). The most reasonable explanation for this unexpected result is that the smaller, less affluent farms are located closer to towns where markets are located while the relatively wealthier farms adopting hybrid live further away from the towns in more quasi-suburban settings. Producers close to markets are also more likely to specialize in higher valued crops such as fruits and vegetables, while producers farther away from markets would be more likely to grow lower-valued crops such as maize. Those conditions would create a positive effect for Market distance though opposite to prior expectations.

The gender variable's significant positive sign in the ordinal logit model ($p<0.05$; Table 6) means that male-headed households were more willing to adopt hybrid maize. This confirmed the conclusions made by Ouma et al. (2002), Smale and Olwande (2014). Female maize farmers are likely to be more concerned with satisfying household consumption needs than male counterparts who would be more likely engaged in commercial farming.

The dummy variable "age_middle" was significant ($p<0.1$; Table 6) and negatively related with hybrid maize adoption response in the ordinal model, indicating that middle-age household heads were more reluctant to adopt hybrid maize. However, due to the low confidence level and insignificance of the variable "age_older", it is not safe to draw the conclusion that age always has a significant influence on maize varieties adoption. In fact, the influences of age were mixed in former studies. For example, it was significantly positive in the research of *Imazapyr*-resistant maize adoption in Kenya (Mignouna et al., 2010), and was significantly negative in the Southwest Nigeria study (Lawal et al., 2004), in some other cases, it was not significant at all (Ouma et al., 2002; Ouma et al., 2006).

From the results, household education level for primary (Edu_1) and secondary (Edu_2) are not significant, but college and higher education (Edu_3) level was significant ($P<0.1$) and had a positive effect in the model (Table 6). More formally educated farmers have developed a greater preference for hybrid seed and likely have greater access to purchased seed and are more likely to maintain the improved agronomic conditions required for improved seed. This result concurs with a research on adoption of maize production technologies in the coastal lowlands of Kenya which also found formal education had a positive effect on hybrid adoption (Wekesa et al., 2003).

The Occupation variable is significant in the model ($P<0.01$; Table 6). According to this result, if the primary occupation of the household head is farming, the household is more likely to adopt hybrid maize. One possible explanation is that farm households could have a greater willingness and feel more confident to adopt a new technology such as hybrid maize than households where farming occupies at best a secondary role in securing household welfare. Ordinarily, if the household head has a profession other than agriculture, then household has off-farm income. Therefore, the significantly positive sign for the Occupation variable can also explain that the odds for hybrid adoption will decrease if the households have off -farm income. This result confirmed the finding from Wekesa et al. (2003).

The variables household size, farm acreage, credit and extension visits were not statistical significant at any of the levels considered in this paper ($P>0.10$). However, a major benefit in logit modelling is that the model determines the relative importance of the independent variables to explain the dependent variable, whether the independent variables are significant or not (Ueckermann et al., 2008). Household size measures labor availability. Non-significant association indicates that labor adequacy is no longer a strong influence on improved seed adoption, a result that differs from former findings (Kebede et al., 1990; Ouma et al., 2002). Credit use was found to have great positive influence on new technology adoption in former research (Smale et al., 2001; Wekesa et al., 2003), but in this paper, credit use is not significant. On one hand, the sample size is comparably small: Among the 444 respondents, only 15 households claim to have used credit before. On the other hand, the distinction between credit used and credit accessibility is difficult to observe (Doss, 2003). The limited credit uses implies that access to credit may be a major constraint for households with low income to adopt hybrid varieties. The effect of extension visits is insignificant. This variable may have been affected by transportation, regional population density, and current adoption rate. Given that the mean extension visit time shown in Table 3 is 5.20 for OPV-only households, 5.67 for grow-both households and 2.99 for hybrid-only households, this may indicated that extension officers have little impact on hybrid maize adoption in recent years, and extension officers have low motivation to visit high adoption rate households.

Conclusions

In Africa, hybrid maize varieties will continue to play an important role in securing food needs for growing populations that are becoming affluent and demanding more food products. Hybrids are also expected to play an important role in the 21st century as Africa transforms its agriculture from the traditional land abundant agricultural paradigm to a new paradigm science-based under conditions of shrinking land and labor supply. The role of biotechnology will likely be significant and hybrids will be important players. Since developing Genetically Modified (GM) products is costly, with large fixed costs, the seed industry will likely need to make careful choices on which varieties to use as the platform GM plants. Hence, research such as presented in this paper provides valuable information for the industry as it begins planning for the GM product lines. Results from this paper suggest that the seed industry needs to continue monitoring household preferences for maize varieties across a broad spectrum of attributes. While technical merits of higher yields maintain a dominant role in hybrid maize popularity, it occupies less than half of the importance attached to hybrid maize performance. Attributes that could potentially be addressed through plant biotechnology breakthrough such as early maturity, drought escape, plant protection, and taste qualities occupy nearly equal shares. Such new developments will be are necessary since according to model results since OPV maize was found to perform better than hybrid maize in drought escape and taste. Therefore, maintaining and improving yield potential, and improving taste of green maize are the key for future maize variety development. Socioeconomic conditions were also found to have a significant effect on hybrid maize adoption. Farm households with presumably lower income and wealth, that is, those with less education, had a lower likelihood of adopting hybrid maize. Promoting the use of hybrid maize will hence require increased efforts to extend hybrid maize to households with less knowledge and trust of new technology. Similarly, given the near complete lack of credit in the study area, reducing the input costs and implementing credit contracts would likely vastly contribute to the future adoption of new maize varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessing environmental and social impacts of the oil palm industry in Ghana: A project synthesis

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The oil palm industry has many positive benefits, particularly as a key source of livelihoods for rural dwellers, but it also has negative impacts on the society and environment. For instance, poorly planned oil palm cultivation can increase the rate of natural forest loss, and contribute to unfair labour conditions on plantations and processing mills. It is therefore important for sustainable oil palm project initiators to understand the environmental and social effects of the industry, to be able to design appropriate interventions. Using a survey method, questionnaires were administered to different stakeholders in selected oil palm plantations and processing mills to generate both qualitative and quantitative data for assessing the social and environmental impacts of the industry. The environmental and social impact assessment was done within the framework and guidelines of the Roundtable on Sustainable Palm Oil (RSPO). The assessment also applied a holistic approach by diagnosing the direct, indirect and sector-wide cumulative impacts. It was found that, in most cases, the social and environmental indicators assessed from the respondents do not comply with the guidelines of national legislation and the Ghana interpretation of the RSPO principles. It is prudent for sustainable oil palm projects to provide opportunities for plantation and mills owners and workers to acquire, and share knowledge on the effects of their activities on the society and environment. Project interventions must be formulated to mitigate negative impacts of the activities of production and processing to ensure sustainability of the oil palm industry.

Key words: Environmental, oil palm, mitigation measures, sustainable palm oil, plantations.

INTRODUCTION

Palm oil is profitable for many producers. It also offers livelihoods and provides social amenities for many rural dwellers in developing countries (Tan et al., 2009; Wilcove and Koh, 2010). Oil palm production, processing and distribution have important economic impacts through rural employment creation and poverty reduction (Henson, 2003). The high demand for palm oil and it products have resulted in a rapid expansion of oil palm

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cultivation across the world. Due to the lack of land availability in Southeast Asia, large expansion of the oil palm industry is expected in sub-Saharan Africa, particularly in West-Africa where land with suitable agro-ecological conditions is available (Rhebergen et al., 2016). The oil palm industry in Ghana has developed over the last two decades into an important industry in the agricultural sector of the economy (Kabutey et al., 2013). The industry plays a key role in enhancing the incomes of rural people (GoG, 2010), and especially provides livelihoods for 80% of smallholders. The activities of the industry however contribute also to environmental degradation. Most producers favour the economic gains from the industry over developing sustainable production (Koh, 2008; Basiron, 2007). This has led to environmental degradation, social unrest and water pollution in many oil palm growing areas. Sustainable palm oil production is thus needed if the country is to continue benefiting from the industry. Sustainability of palm oil implies cultivating and processing oil palm in an accepted economic, social and environment manner (Tan et al., 2009). By assessing the environmental and social impacts of oil palm production and processing, this article explores options for minimising the negatives and suggests how to maximise the positive impacts of the industry.

The oil palm industry has become one of the most intensely debated industries in recent times, not only because of its positive benefits but also the negative impacts it causes to society and the environment (Laurance, 2009). For instance, poorly planned oil palm developments can increase the rate of natural forest loss, create social and environmental problems and reduce local peoples' control over land in favour of large corporations (World Bank, 2010). The development of oil palm has caused deforestation, resulting in significant secondary external impacts such as water pollution, soil erosion, and air pollution (Obidzinski et al., 2012). These challenges in the industry must be addressed, but to design interventions that will be sustainable for and beneficial to the actors in the industry, it is important to understand the existing situation and perspectives, so as implement interventions that will provide appropriate solutions (Osei-Amponsah and Visser, 2016). Project designed with an objective to promote the production of sustainable palm oil, must therefore first understand the environmental and social impacts of the oil palm industry, and how best to mitigate them. There is an urgent need for environmental sustainability in the oil palm industry, in terms of producing oil palm fruits and palm oil, and also the capacity to absorb waste products in an environmentally and socially friendly manner. Thus, the environmental and social impact assessment is a laudable approach for decision-making in the oil palm industry (RSPO, 2016), and also enables stakeholders to design and implement sustainable production projects. This article provides insights on the environmental and social impacts of the oil palm industry in Ghana, within the context of the Roundtable on Sustainable Palm Oil (RSPO) guidelines. It also proposes mitigation measures to address the negative impacts to provide options for enhancing productivity and profitability of the oil palm industry.

The RSPO is an international non-profit association that aims to bring together multiple stakeholders to develop and implement strategies regarding the production of sustainable palm oil (RSPO, 2016). The RSPO defines sustainable palm oil production as a legal, economically, viable, environmentally appropriate and socially beneficial management and operations (RSPO, 2016). Within the context of RSPO, sustainability can be realised through the Principles and Criteria applicable to the management of oil palm plantations and mills. Under the RSPO Certification System (RSPO, 2007), there are eight principles that companies must comply with in order to be certified as a sustainable palm oil producer. This article dwells on Principle 7, which focuses on social and environmental impact assessment. The aim of this study is to investigate the nature and approximate scale of important environmental and social impacts of the oil palm industry in Ghana, which would form the basis for a sustainable production project to design appropriate interventions.

The next section presents the method used for the study, followed by the results of the environmental and social assessments. At the end, the conclusions are summarised in a tabular form (Table 2).

METHODOLOGY

A survey was conducted between February and March, 2013 with standard questionnaires addressing all possible environmental, health and safety and social sustainability issues. Sites purposively selected for the study are 33 mills- (3 large, 8 medium) and 17 small-sized Crude Palm Oil (CPO) mills and it associated oil palm plantations, as well as 5 small-scale Palm Kernel Oil (PKO) mills, all in the Ashanti, Eastern, Central and Western regions of Ghana.

The article applied a holistic approach to environmental and social impact assessment by analysing the totality of impacts (direct, indirect and sector-wide cumulative). Attention was also given to the interrelation between environmental, social and socio-economic impacts, and the actual, potential negative as well as positive impacts assessed (Table 1). Several of the themes listed were only surveyed for large and medium-sized mills because they are not relevant for small-sized mills.

The Ghana National Interpretation of the Principles and Criteria of the RSPO was adapted as a basis for assessing sustainability in the industry. The research team also used the value chain approach, by looking at the social and environmental impacts of the different components of the oil palm value chain. The analysis starts with the CPO mills, which are seen as the central unit in the value chain (Figure 1), as well as the different relations these mills have with the suppliers (e.g., outgrower schemes). However, the study does not look at the sustainability issues of the chain elements of transport and trade.

Data were collected through multiple choice questionnaires designed for each category of value chain actor. To the extent

Table 1. Themes applied in the study (Author's Compilation).

CPO/PKO Mills	Oil palm plantations
Environment	
Legal compliance	Biodiversity protection
EIA/EMP and environmental monitoring	Erosion
Waste management	Water pollution
Water use	Fire control
Energy use	Fertilizer use
Water pollution	Pesticide/herbicide use
-	Waste management
Health and safety	
Cleanliness	Cleanliness
Worker's health & safety management	Worker's health & safety management
Worker's health & safety training	Worker's health & safety training
Accident and emergency procedures	Accident and emergency procedures
Use of personal protective equipment	Use of personal protective equipment
Social issues	
Legal compliance	Legal compliance
Social impact assessment	Minimum wage
Minimum wages	Child labour
Housing and restroom facilities	Conflicts over land
Freedom of association	Local employment
Child labour	-
Sexual harassment and violence	-
Communication with workers	-
Communication with communities	-
Complaints and grievances	-
Conflicts over land	-
Local employment	-
	-
Food security	-
General description on how oil palm has influenced food production and food prices in a Region	-

Table 2. Summaries of environmental and social issues in oil palm mills and plantations.

Key issues	Mills				Plantations		
	Large	Medium	Small	PKO	Large	Medium	Small
Effluent discharge							
Organic waste and soil fertility management							
Air pollution/Smoke							
Energy efficiency/Firewood use							
Chemical waste management							
Health and safety awareness and training							
Use of personal protective equipment							
Child labour							
Organisation of workers/Users (association)							
Adequate housing and restroom facilities							
Land conflicts and conflict resolution							

Table 2. Contd.

Legend	Not a priority Moderate priority/Risk High Priority/Risk	

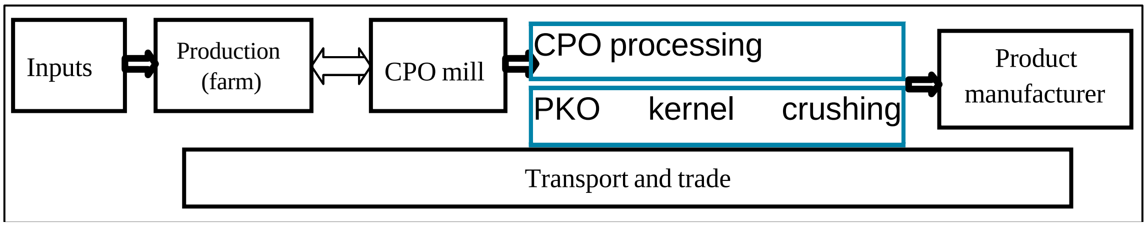

Figure 1. Value-chain model of oil palm (Author's own elaboration).

possible, each issue was given three possible answers which represent poor, medium and good practice. For each question, the enumerators also noted observations or specifics for the interviewee mill or farmer. There were also open questions for several subjects, including practices on the use of organic fertilizer, agro-chemicals, discharge of effluent. The subject of the effect of oil palm mills and plantations on local food security was mainly treated in a qualitative manner. The study also reviewed several national and international reports on environmental and social impact assessment on the oil palm industry.

RESULTS AND DISCUSSION

This section presents the findings of the study within the RSPO framework; it also discusses and proposes mitigation measures for the pertinent issues. The results of the environmental assessment (at mill and farm levels) are first presented, followed by the social impact assessment.

Environmental issues at the mill level

For the indicators of environmental laws and regulations, Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP), the RSPO requirements: Evidence of compliance with relevant legal requirements; a documented system, which includes written information on legal requirements, and a mechanism for ensuring that they are implemented. Within the Ghanaian context, the EIA and EMP require from the industrial actors, a documented environmental impact assessment, an EPA permit and compliance with the permit conditions (according to Environmental Assessment Regulations, LI 1652, 1999). The study found that, among medium and large-scale mills, there was a high awareness of the national environmental laws and regulations. The mills were aware of the existence of the RSPO principles through their interactions with sustainable palm oil projects. It was also evident that efforts are being made to comply with the national environmental laws and regulations, however, often in a non-systematic manner. Among small-scale mills, there was limited awareness, only 27% knew how to comply, the others were either not aware or did not know how to comply. Two large-scale mills had put in place the necessary measures to comply with the stipulated permitting conditions from the EPA and action plans in the EMP. Most of the medium sized mills (63%) had, however, not prepared these documents. For those that had been prepared (37%), there was no evidence that adequate measures were taken to implement the EMP. To improve on the situation, it will be necessary for sustainable palm oil projects in collaboration with EPA, to develop guidelines for large and medium-scale palm oil mills and plantations on the relevant environmental and health and safety standards in Ghana. Most small-scale mills are not aware of these measures. It will be important to raise awareness in order to improve the environmental and health and safety conditions.

The RSPO indicator on effluent disposal requires the monitoring and documentation of effluent parameters, which should be part of the quarterly monitoring returns to EPA; Appropriate treatment of mill effluent and regular monitoring of discharge quality, which should be in compliance with national regulations. Large mills were found to typically generate high volumes of palm oil mill effluent (POME). They treated the effluent prior to disposal, principally by using treatment ponds, and/or for land application. The effluent quality however did not meet the EPA's National Effluent Quality Guidelines (NEQG) for disposal into natural water bodies. The medium-sized mills also generated significant quantities of effluent, but this was often not adequately managed by about 75% of them (Figure 2). In these cases the effluent was discharged without sufficient treatment. In two cases, medium-sized mills discharged effluent into nearby water

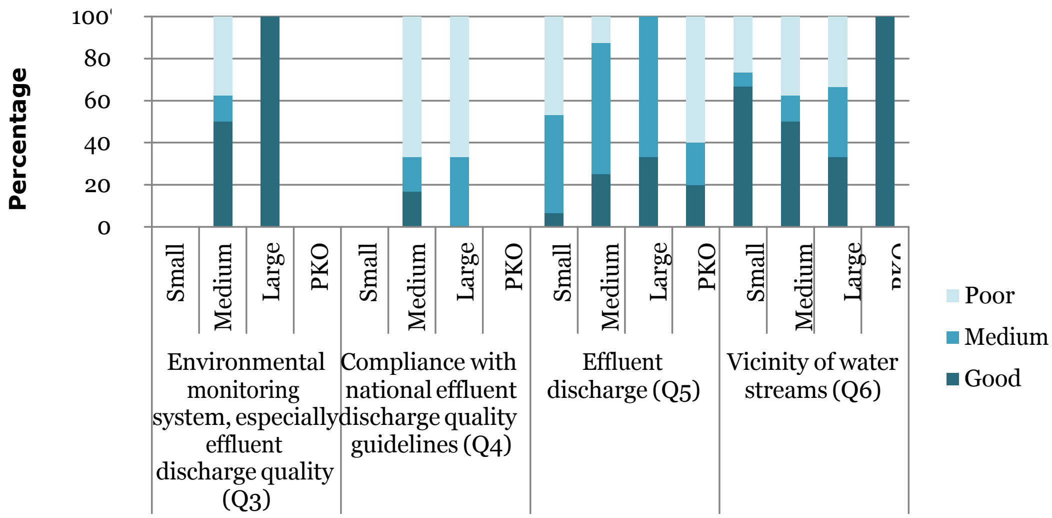

Figure 2. Effluent management at mills (Author's own elaboration).

streams, thus posing a serious risk to water pollution. In 25% of the cases, the effluent was managed but only in one case did it fall within the national norms. For small-scale mills, the effluent generated was in small quantities, this comprised liquid waste usually from the boiling of fruits. In 50% of the cases the remaining effluent was discharged on nearby land and/or in streams, rivers without any treatment. The PKO mills also generally did not take any adequate measures to dispose effluent.

Construction, operation and maintenance of multi-chambered oil traps/fat pits as an initial are proposed as a treatment measure for the POME. The oil to be recovered from this may be sold to soap manufacturers. The treated POME may also be applied directly onto land as organic fertilizer, or it can be composted with Empty fresh bunches (EFBs) and applied to the plantation. A study on POME also suggests ultrasonicated POME can be used as sustainable feedstock for dark fermentation-based bioH 2 production and MFC-based bioelectricity generation (Leaño et al., 2012). For small-scale mills, investment in more efficient oil extraction equipment to reduce the oil content and organic matter load of the effluent is required. A small temporary effluent retention facility/oil trap that permits the recovery and reuse of some of the oil from the effluent is also proposed.

For the management of organic wastes, RSPO requirements refer to nutrient recycling strategies that include EFB, POME, palm residues after replanting and any use of biomass for by-products or energy production. The results show that the largest volumes of organic wastes were recycled as organic fertilizer, but large volumes were also used as fuel for the mills. For small-scale mills, most organic wastes were used as fuel. The mills generated a lot of organic wastes (empty fruit bunches, fibres, kernel shells, palm kernel cake, boiler ash). All large-scale mills (100%) and most (75%) of the medium-scale mills generally had adequate disposal systems. One medium-sized mill used all organic wastes as fertilizer. One large-sized mill used 70% of EFBs as mulch and the remaining 30% as fuel, while another one used 100% as mulch. The large or medium-scale mills used all fibre and kernel shells as fuel for heating the water in the mill. Most medium-scale mills used all or part of the EFBs as mulch in the plantation, and the remaining is burnt. Small mills usually used the EFBs and fibres for boiling the oil palm fruits. Kernels or kernel cake is commonly sold to be used as feed for piggeries.

The RSPO requirement on management of toxic and hazardous wastes is the development and implementation of a waste management and disposal plan to avoid or reduce pollution. All large-scale and medium sized mills were found to collect toxic and hazardous wastes and dispose of them at approved sites or for reuse. Of the small-scale mills, most collected and reused toxic and hazardous waste (60%).

For energy or fuel use, RSPO requires regular monitoring and documentation of renewable energy use per ton of CPO or palm product in the mill; monitoring and documentation of direct fossil fuel use per ton of CPO. All the large-scale mills and most medium scale mills (88%) collected data on their energy consumption. In addition to the EFBs as sources of energy they used diesel generators or electricity as firewood (records indicated only around 1000 kg per month). There is also use of residual oil as fuel which generates hazardous air pollution and is illegal. The small-scale CPO mills were found to make use of limited quantities of firewood (in addition to the use of EFBs and fibers as fuel). All PKO mills made use of firewood, in slightly larger quantities than the CPO mills.

In the case of air pollution by smoke, the large and medium-scale mills had smoke stacks installed to take up the smoke generate from the working environment. The stacks were sufficiently high to allow for adequate air dispersion. Although all large-scale mills still create some air pollutants, these are within the national ambient air quality norms. Most (62%) of the medium-scale mills produce air pollutants which are not within the standards. The issue of air pollution by smoke was significant among the small-scale mills, where the smoke generated was generally within the breathing zone of workers. None of the small-scale mills had taken any measures to install a chimney. More than half of the PKO mills (60%) did not take any measures against smoke pollution. The results indicated significant problems with air pollution, some studies elsewhere corroborate these findings (Dudgeon et al., 2006). The RSPO requires the identification and monitoring of all polluting activities, which include smoke, and compliance with national regulation on emissions. The national ambient air quality guidelines are sulphur dioxide emissions for 24 h within 150 mg/m^3. The large-scale mills are within this norm, but most medium-sized mills and small-scale mills do not meet this standard. Within this context it is proposed that sustainable production projects should formulate interventions that assist medium-scale mills to set up chimneys. The small-scale mills should also be supported to construct chimneys in the roof of their sheds.

The study identified that all large-scale mills collected data on their water consumption, but most of the medium-scale mills (70%) did not. Water was also used for irrigating seedling nurseries and most medium-sized mills have their own water wells but did not register water use. RSPO requires monitoring of mill water use per ton of FFB; it was not done by the majority of small and medium-sized mills.

Environmental issues plantations

The RSPO indicator on biodiversity protection requires the documentation on the status of rare, threatened or endangered species and high conservation value habitats, if any, that exist in the plantation or that could be affected by plantation management. If these are present, appropriate protection measures must be adopted (by group managers and for large-scale plantations in management plans). For most small and medium-scale plantations, there was limited awareness and no protective measures were taken. The study showed that all large-scale plantations take protective measures for biodiversity, while it was 43% in the case of the medium-scale plantations. This included biodiversity plots, buffer zones and no-hunting regulations. On the contrary, small plantations generally did not take such measures in their plantations, as discussed in other studies (Fitzherbert et al., 2008; World Bank, 2010). Of the medium-scale mills, 71% stated that they were planning expansion of their plantation, which is expected to take place on agricultural lands. Of the small mills, only 40% have plans for expansion of related plantations, but the size of the expansion is always very limited (less than 2 hectares). For medium-scale mills, the study proposes the creation of awareness on the need to maintain biodiversity plots and replant with forest trees at selected sites, e.g. along river banks. Sustainable production projects should also sensitize small-scale plantations to desist from encroaching on river banks and swampy areas to cultivate oil palm.

A study by Rhebergen et al. (2016) also found opportunities for large-scale oil palm plantation development is limited, however, and recommended smallholder production or yield intensification on land already planted as a feasible strategy for oil palm expansion in Ghana. This could also reduce the requirement for further land clearance for new plantations to meet the growing demand for palm oil.

For the indicator on erosion and other protective measures for sensitive areas, the RSPO requires management strategies for soil erosion on slopes between 17 and 30%. It also requires protection of local water courses and wetlands, including maintaining and restoring appropriate riparian buffer zones. The survey showed that for the protection of sensitive water areas (swamps, river banks), the reference to required buffer zones varies widely, from 4 to 30 m zone. About 30% of the medium-sized mills do not take such measures within their plantations. Almost all large- and medium-scale mills take erosion control measures in their plantations. The use of cover-crops like *Pueraria* or *Centrosima* was common with large scale plantations. The small-scale farmers shunned its use with the reason that it becomes a habitat for reptiles especially snakes. Large and medium-scale plantations also use palm fronds heaped along the slope, sub-soiling or construct terraces along the slopes. None of the small-scale plantations was found to take adequate anti-erosion measures in their plantations. Of the small-scale mills, 40% were aware of the requirements and took measures, 27% were aware but did not take measures and the remaining were not aware. Thus, many small-scale farmers did not establish sufficient protective measures as they utilized all the land available including swamps and the banks of water bodies. Buffer zones for water bodies were practiced by some small- scale farmers, not as a result of the rules and regulations but due to traditional practice to reserve water for use when they go to work on their farms.

The RSPO requires that no fire is used for preparing land for replanting. Only some small-scale plantations do occasionally use fire when preparing land.

All large and medium-scale plantation owners were found to take measures to avoid and control fire, as well as 80% of the small plantation owners. These measures are mainly a system to monitor fire incidence and having a fire belt. Only a few have firefighting equipment or a fire certificate. None of the large- or medium-scale plantation owners used fire to manage wastes. Of the small plantation owners, 40% frequently used fire in their plantations.

The RSPO requires practices that maintain soil fertility, or where possible improve soil fertility to a level that ensures optimal and sustained yield. Some of these practices are recording of fertilizer inputs and application are maintained; documenting of periodic tissue and soil sampling to monitor changes in nutrient status; stacking of palm fronds along the contours in the farm. Of the large-scale plantations, 66% commonly used organic fertilizer in their plantations and 33% occasionally. Of the medium-scale plantations, 71% used organic fertilizer in their plantations, 14% occasionally and the remaining (14%) not at all. Of the small-scale farmers, only 33% used some organic fertilizer. As organic fertilizer, EFBs are commonly used as mulch and palm fronds are arranged between rows of palm trees to decay. The use of poultry manure (application once a year on mature palm 12.5 kg/tree and on young palm 6.5 kg/plant), was mentioned. In a similar environmental assessment of the oil palm industry in Thailand, 26 options were identified for reducing the environmental impact of palm oil production (Saswattecha et al., 2016). Their analysis showed that empty fruit bunch (EFB) combustion, wet scrubbers and pre-heating fiber are the most effective in reducing multiple impacts. Among these, EFB combustion resulted in the largest environmental improvement, but at relatively high costs. Several options were found to be not only effective, but also generate a positive net return. These included cover crops, mulching EFB, EFB composting, EFB pellets production, oil loss recovery from decanter cake and pre-heating fiber. The most paying options are mulching EFB, harvesting ripe fruits and cover crops.

All large-scale plantations surveyed used chemical fertilizer and of the medium-scale plantations, 29% used chemical fertilizers on their plantations. Use of organic or inorganic fertilizers was mainly done during the seedling and young stages of the plants (between 1 and 3 years). Of the small-scale plantations, 13% used chemical fertilizer, while 67% did not at all. While the large-scale plantations established nutrient management plans, medium and small-scale plantations lacked the basic knowledge on soil fertility management practices.

In addition to this indicator, the RSPO requires that agro-chemicals are used in a way that does not endanger the environment or human health. There is no prophylactic use of pesticides, except in specific situations identified in national best practice guidelines. There are specific requirements for the handling and storage of agro-chemicals. Most small and medium-scale plans did not comply with these requirements. All large-scale plantations were found to use agro-chemicals, mainly herbicides for young plants, and also had an integrated pest management (IPM) plan. The medium-scale plantations, 43% used of agro-chemicals while none has an IPM plan. Also, none of the small-scale plantation owners had such a plan. Of the small-scale plantation owners 80% did use herbicides, although in small quantities. Plantation owners, especially the medium-scale ones, commonly refer to the fact that more herbicides are used to control weeds because of the increasing cost of labour, especially in Eastern, Ashanti and Western regions. The most common type of herbicide used is Gramoxone (Paraquat). Other agro-chemicals used are Roundup (Glyphosate) and Dursban, which are both banned chemicals.

For waste management, the RSPO requires that: Producers develop and implement a waste management and disposal plan. The large plantations were found to collect wastes (plastics, empty containers) used in the plantations and dispose these in an appropriate way. About 50% of the medium-scale mills also disposed waste properly. The small-scale plantations on the other hand buried the containers in the plantations, burn them or leave them on the ground. To address this challenge, producers should be encourage by sustainable projects to create collection points for chemical wastes; and that instructions on manufacturer's labels are followed.

Occupational health and safety-mills and plantations

The RSPO requirements state that producers and processors of oil palm should have a health and safety policy, which is implemented and monitored. All precautions attached to products should be properly observed and applied by the workers. Accident and emergency procedures should exist and instructions should be clearly understood by all workers. Records should be kept of all accidents and periodically reviewed. Workers should be covered by accident insurance and calculation of Lost Time Accident (LTA) rate should be standardized. The results showed that all large-scale mills and their plantations had a safe and clean environment. They were aware of the national health and safety regulations, and had a plan for it. They also had an accident and emergency plan for the mill. Fifty per cent of the medium-scale mills had a health and safety plan and 25% had an accident and emergency plan. In the medium-scale mills, 38% signage can be improved, while in 50% of the cases there was no signage. Of the small-scale mills, generally, there was a moderate level of awareness on health and safety issues. Many are aware of the health and safety regulations but 45% did not know how to comply. All large-scale plantations gave frequent training in an organized way on health and safety issues. Of the medium-scale mills, 25% gave frequent training, 40% occasionally and 35% not at all (trainings may be provided by external agents, such as fire departments or health centres). Of small-scale mills and plantations, 43% occasionally underwent training. Occasional training usually refers to informally discussing health and safety

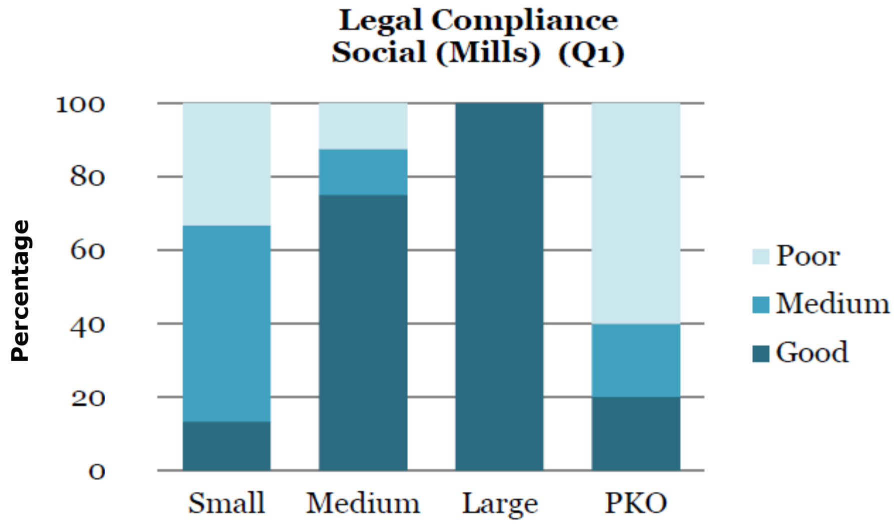

Figure 3. Legal Compliance in oil palm plantation mills (Author's elaboration).

issues and providing instructions during weekly meetings. The RSPO also requires that adequate and appropriate protective equipment be made available to all workers to cover all potentially hazardous operations, such as pesticide application, land preparation, harvesting and burning.

As part of their health and safety management systems, all large-scale mills surveyed, provide and enforce the use of PPEs. In the medium-scale mills however, 37% provided sufficient PPEs, while for the small-sized mills, 40% supplied some PPEs. To enhance the use of PPEs, the study proposes regular training on the use of the PPEs either by the mill owner or a designated health and safety officer.

Social-mills and plantations

The awareness of social and labour laws, regulations, social impact assessment and a social management plan is an important indicator; and the RSPO requires that labour laws, union agreements or direct contracts of employment detailing payments and conditions of employment (e.g. working hours, deductions, overtime, sickness, holiday entitlement, maternity leave, reasons for dismissal) are available in the languages understood by the workers or explained carefully to them by a management or union official. This is different from the focus of our survey which was oriented at the awareness of the employers or owners, rather than the workers.

As indicated in Figure 3, among large-scale mills and their plantations there were good awareness of the national social and labour laws and regulations. The large mills had prepared EIAs and an EMP, and had put in place the necessary measures to comply with the stipulated permitting conditions.

In addition to the legal compliance, RSPO requires that pay and conditions for employees and for employees of contractors always meet at least legal or industry minimum standards and are sufficient to provide decent living wages. All the three classes of mills and plantations were found to pay at least minimum wages. In most cases workers are paid more than GHS4.48 (which was the minimum wage until April 2013), the minimum wage has increased to GHS 5.83 and currently to GHS 7.00 (in 2015). Workers have so far been paid above minimum wage because if the contract workers are paid below minimum wage, they will leave the mill plantation for alternative activities. It is also important that_employers respect the right of all personnel to form and join trade unions of their choice and to bargain collectively. Where the right to freedom of association and collective bargaining are restricted under law, the employer facilitates parallel means of independent and free association and bargaining for all such personnel. The study found that all large-scale mills had high awareness on freedom of association. They encouraged workers to be unionized and belong to the Ghana Agricultural Workers' Union (GAWU) and other welfare groups present. For 62% of medium-scale mills, the workers were organized, while 38% there was only awareness. Small-scale mills generally did not encourage any formal type of organization by the workers or users.

It is suggested that the development of an association that unites in a certain locality the owners, millers and users of existing small-scale (CPO and PKO) mills be stimulated by interested sustainability projects. This organization could be the focal point for the projects to communicate and disseminate messages on environmental, health, safety and social issues and also offer training services.

Within the RSPO framework, producers and mill owners have to provide adequate housing, water supplies, medical, educational and welfare amenities to national standard or above. Among the facilities to be provided for workers there is need for appropriate and sufficient (in quantity) sanitary, washroom and restroom facilities, with lighting, and these facilities should be clean. We found that 66% of the large-scale mills had such facilities for workers, including canteen and toilets. Among the medium-scale mills, 25% did not have any such facilities while 50% had some facilities and only 25% had adequate facilities. It is therefore important that medium-scale mills improve on facilities for workers, by at least providing appropriate and sufficient sanitary, washroom, restroom facilities with lighting.

Child labour, is a relevant indicator in the RSPO. It was found that, among the large-scale and medium-scale mills and their plantations there was good awareness of the child labour regulations and there was no evidence of any cases of child labour. This was also the situation in PKO mills (small or medium). However, among small-scale mills and plantations, the situation was quite different. While the owners were generally well aware (86% for mills and 70% for plantations), in some cases there was evidence of child labour (14% for mills and 38% for plantations). There was also good awareness of regulations on sexual harassment and violence and there was no evidence of any violations.

The RSPO requires open and transparent methods for communication and consultation between producers and/or mill owners, local communities and other affected or interested parties and well as mutually agreed and documented system for dealing with complaints and grievances, which is implemented and accepted by all parties. All the large-scale mills had fora for internal communication as well as regular fora or events for communicating with the surrounding communities. They also had in place formal mechanisms for complaints and grievances and these were fully resolved. Medium-sized mills generally had fora for internal communication (82%), e.g. a biannual meeting, where supervisors met workers. However, none of the medium-scale mills had regular fora or events for communicating with the surrounding communities, while most had occasional events (75%). In one case there was annual interaction with the chiefs of surrounding communities. Most also had in place formal mechanisms for complaints and grievances (64%), but some had informal mechanisms only (36%).

In the case of local employment, it was found that in the large-scale mills and plantations 75% of workers were from local communities. This was generally also the case for medium-scale mills and their plantations. For the small-scale mills, 14% did not have any local workers and labour was on contractual basis. Morin (2013), in a similar study suggested that to reduce the negative social impacts and trade-offs of oil palm plantations and maximize their economic potential, government decision makers need to restrict the use of forested land for plantation development, enforce existing regulations on concession allocation and environmental management, improve monitoring of labour practices, recognize traditional land use rights, and make land transfer agreements involving customary land more transparent and legally binding.

Food security

In the Ashanti Region, oil palm production has increased significantly over the last 20 years, especially following a Presidential Special Initiative (PSI) on oil palm production. However, cocoa has also increased over this period and some farmers are diversifying into cocoa production. For instance, in the Adansi area production of food crops has reduced significantly and food prices have increased over the period since farmers prefer the cultivation of oil palm and cocoa. There was, however, sufficient food being cultivated to serve the area. In the Juaben area, most respondents saw no relationship between food production and increase in oil palm development, since according to them, food was abundant and reasonably priced although most farmers seemed to prefer oil palm and cocoa farming.

In the Eastern Region, oil palm plantations have been in existence for over 30 years and have expanded over the years. There was still land available for food crop cultivation which had not been utilised because the farmers preferred oil palm plantation development as this gives more security of income. The income from the oil palm industry was enough to buy food. Whereas, food was initially exported from this Region, now food is largely imported and prices are higher. This may be partly due to the production of oil palm. In the Western Region the impact of oil palm expansion on the production of food crops was generally unclear. Farmers deferred the production of food crops to the production of cocoa, rubber and oil palm. Oil palm is now being replaced by rubber. Most youth were also engaged in ‘galamsey’ (illegal mining) and therefore not willing to engage in food crop production since they did not find it lucrative enough. There has been an increase in the prices of food as a result of the shortage of food in the area but this cannot be attributed to oil palm production only.

Oil palm development in the Central Region, started about 30 years ago. Plantation development has resulted in decrease in food production as farmers find oil palm cultivation a more lucrative and reliable source of income. Oil palm was usually intercropped with food crops up to about 4 years old, when the canopy was fully formed.

Food crops such as maize, cassava were produced locally and more exported, but these are now being imported into the Region. Now rice has become the staple crop (being imported). In the southern portion of the

Region, near the coastal areas, however, food crops did not thrive very well and therefore farmers preferred to grow oil palm. Some oil palm companies make available land to the workers to grow their own food crops. Overall, oil palm was seen as a lucrative crop as it provides regular incomes throughout the year. Oil palm has replaced food crops in the 4 different regions. From exporting local food crops (maize, cassava), the Eastern and Central regions have become food importers and the diet seems to have changed as well (more towards rice). Food prices have gone up in all regions. It is not possible to attribute these changes to oil palm only, as other crops have also expanded (cocoa, rubber) and there is an influx of people involved in mining activities (Western and Eastern region).

Conclusion

This article have assessed the environmental and social impacts of the oil palm industry in Ghana, in order for projects to have relevant insights and design evidence-based interventions to enhance sustainability in the industry. The article summarizes its conclusions in a tabular form (Table 2) to show which environmental and social issues constitute problems and risks for the producers and/or processors in the industry. In most cases, the current situation on the issues shows there is no compliance (particularly for small-scale enterprises) with national legislation and the Ghana interpretation of the RSPO criteria and principles.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Challenges of herdsmen-farmers' conflict in livestock production in Nigeria: Experience of pastoralists in Kogi State, Nigeria

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Herders-farmers' conflict is wide spread and a formidable challenge to livestock production in Nigeria. The study examined challenges faced by pastoralists in conflict with farming communities. A total of 72 Fulani pastoralists from transit camps were used. Data were collected by use of structured interview schedule, focus group discussion and personal observation and analysed using descriptive statistics and factor analysis. The majority (95.8%) of pastoralists were male, married (80%) with mean age of 39 years and average household size of 11 persons. Herding was mainly for prestige and commercial purposes with average farm size of 240 cattle. Conflicts between pastoralists and crop farmers were caused by socio-economic, security, production practices and institution related factors. Consequently, pastoralists had the problems of insecurity of human and animal lives, displacement and economic losses leading to poor productivity. Therefore, we recommend that all stakeholders (government, non-governmental organizations, extension agencies, rural institutions among others) should intensify efforts to build cooperative and peaceful coexistence between farmers and pastoralists through public enlightenment, education and campaign in agrarian communities. Government and NGOs should promptly intervene with aids/compensation to reduce vulnerability, persistence and further spread of conflict of pastoralist-farmer conflict in communities.

Key words: Displacement, economic, environment, livelihood, resource, security.

INTRODUCTION

Globally, livestock contributes about 40% to the agricultural gross domestic product (GDP) and constitutes about 30% of the agricultural GDP in the developing world (World Bank, 2009). It plays crucial and multiple roles in the livelihood of people ranging from food supply, family nutrition, incomes, employment, livelihoods, safety net, draught animal power, manure and sustainable land use for agricultural production (Otte and Knips, 2005; Perry and Sones, 2007; Freeman et al., 2007; Herrero et al., 2010; Pell et al., 2010); and accounts

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for almost 30% of human protein consumption (Steinfield et al., 2006). According to Rosegrant et al. (2001), demand for livestock products particularly milk and meat in sub Saharan Africa is expected to grow by 3.2 and 3.9% per annum between 1997 and 2020 due to increasing population, income growth and urbanization. Similarly, Thornton (2010), reports that food demand for livestock products will nearly double in sub-Saharan Africa and South Asia, from some 200 kcal per person per day in 2000 to around 400 kcal per person per day in 2050. Unfortunately, United Nation (UN) (2014), reports show that the trend of increased demand is currently not matched by a similar growth in local production within Africa. In sub Saharan Africa, productivity remains low and average yields per animal are lower than those in other developing regions (Otte and Knips, 2005).

Livestock sector is plagued by several challenges such as lack of adequate supplies of quality feed and pasture, diseases, weak market network, unavailability of adequate water and poor veterinary services (Kassam, 2009; Peeling and Holden, 2004; Mutibvu et al., 2012). Pell et al. (2010), reiterate that the sector is constrained by institutions, markets and policy as well as technical issues. More recently concern on herdsmen-farmers' conflicts has appeared in literature and policy discourse as one of the formidable challenges facing livestock production (particularly ruminant) in many developing countries.

Manu et al. (2014) opine that conflict emanates from the insatiable nature of human wants; and competitions for scarce resources are the foremost causes of community or inter-group conflicts. Resource use conflicts/clashes according to Adisa and Adekunle (2010), are becoming fiercer and increasingly widespread in Nigeria. A study of 27 communities in central Nigeria by Nyong and Fiki (2005) shows that over 40% of households surveyed had experienced agricultural land-related conflicts, with respondents recalling conflicts that were as far back as 1965 and 2005. Sunday Trust Newspaper as reported by Okoli and Atelhe (2014), shows that about 13 cases of farmer- herdsmen conflicts across states of the federation which claimed 300 lives of the citizens In Kogi State, there have been cases of conflicts between herders and crop farmers in Igalamela/Odolo, Ibaji/Ofu local governments and host of other local governments over crop destruction by cattle, killing of herders and stabbing of farmers following reprisal attack on different occasions.

The majority of pastoralists in Kogi State involved in the livestock industry are Fulani, accounting for about 90% of cattle herd ownership, which makes up 3.2% of the GDP (Koster and de Wolff, 2012). According to Fabusoro (2004), they are the major cattle breeders, providing the main source of meat, the most available and inexpensive source of protein. Fulani pastoralists migrated into Hausa land from the Senegalese Valley in the Western Sudan (Fabusoro, 2007). They first settled in the Sudan/Sahel savanna in Northern Nigeria and were forced out by the deteriorating environmental condition, land degradation and the recurrent drought in the Sudan/Sahel savanna during 1960 to 1970. This accounted for the exodus of pastoralists from their home base to the Guinea savanna and even beyond to the forest fringes in the southern part of Nigeria (Fabusoro, 2007). According to Adisa and Adekunle (2010), and Baba (personal communication) the migration of nomadic pastoralists follows a systematic pattern, dictated by variations in rainfall, grazing stock, pasture and water. Gbaka (2014) reiterates that while continually moving toward pasturage, water sources, salt licks, livestock market, the nature of the terrain that allows for un-impeded movement, protective mechanisms for their livestock against the vagaries of nature, they sometimes avoid the tsetse flies, harsh weather, tribal enemies, livestock bandits, tax assessor, and hostile social environments. Besides, such movement serves as a drought coping strategy which historically helps many pastoralists to manage uncertainty and risk in arid lands and to addresses socio-economic objectives such as access to a diverse range of market opportunities. The migratory nature of the pastoralists is a source of potential conflicts as there is intense competition between pastoralists and farming communities.

Similarly, Gefu and Kolawole (2002), observe that arable crop farmers have not only intensified the use of land but also have been exploring other frontiers for farming. Consequently, farmlands that are normally allowed to fallow for natural rejuvenation of the soil are fast disappearing due to intensification of farming activities; so also are grazing lands such as fadama low-land areas, which have traditionally provided dry season grazing to pastoralists. Blench and Dendo (2003) report that expansion of both fadama and horticulture had negative consequences for pastoralists because the southern dry season movement characteristic of Nigerian pastoralists depended on unimpeded access to riverbanks, where grass could be found when the surrounding land was largely devoid of forage. This often generates contention over grazing land, water points and, in some cases, over property rights like land ownership.

Pastoralist-farmers' conflict in Nigeria has persisted and stands out a threat to national food security, livestock production and eradication of poverty with pastoralists often regarded as the most vulnerable. Pastoralist-farmer conflicts not only have a direct impact on the lives and livelihoods of those involved, they also disrupt and threaten the sustainability of agriculture and pastoral production in West Africa (Moritz, 2010). The two groups make their livelihood within the same geographical, political, and socio-cultural conditions, which may be characterized by resource scarcity (Braukämper, 2000) or political inequality (Bassett, 1988) and population pressure. Pastoralists are believed to be more vulnerable compared with farmers because their cattle can be confiscated and/or seized and released only on payment of a fine. Besides, sometimes they are in the minority and could lack political power to their advantage. Unlike farmers who are increasingly integrated and with appreciable power to maneuver issues, pastoralists often lack western education, stay with increasingly in-appropriate models of land tenure and are unable to work within the political system to their advantage (Blench and Dendo, 2003). Additionally, many development initiatives and programmes for addressing rural poverty and resilience have exacerbated the problem of conflicts with greater risk for pastoralism in the Nigeria. Therefore, the study examined challenges of herders-farmers' conflict for livestock production in Kogi State. It specifically sought to:

1. Describe the socio-economic characteristics of pastoralists in Kogi State;
2. Examine conflict factors as perceived by pastoralists and
3. Ascertain challenges faced by pastoralists in Kogi State.

METHODOLOGY

The study was carried out in Kogi State, Nigeria. The state lies between latitudes 6° 33[1] and 7°49[1]N and longitudes 6°45[1] and 7° 49[1]E. It has a population of 3,278,487 inhabitants (National Population Commission, 2006) with large expanses of fadama lowlands in river basins and stretches of tropical rainforest in the south and western belt of the state. Agriculture is the principal means of livelihood of about 85% of the population with the dominant crops being yam, maize, cassava, cocoyam and tree crops. Other occupations of the inhabitants of the state include fishing done by communities living along the river banks and trading. The livestock kept include cattle, sheep, goats and chicken on free range basis. The migrant pastoralist graze herds mostly in grassy areas of fadama lowlands and the river banks.

The population of the study constituted all Fulani pastoralists in the state. A survey design was used for the study. Out of the 21 local government areas (LGAs) in the state, 16 LGAs are mostly associated with farmer-herder conflict. Nine were purposively selected for the study, representing the three primary agricultural zones of the state. In each LGAs which consists of four transit camps, two herders were randomly selected from each transit camp giving a total of eight herders from each LGAs. This gave a total of 72 pastoralists used for the study. Data were collected through use of structured interview schedule, focus group discussion and personal observation. The respondents provided information on their socio-economic characteristics in the areas of sex (male or female), age in years, marital status measured at nominal levels (married, widowed, divorced and single); educational level elicited as no formal education, primary education, secondary school attempted, secondary school certificate(completed secondary school), tertiary (ND, HND, NCE, BSc); Koranic education, and M.Sc./ PhD. Household size was measured by the number of persons living under the same roof and feeding from the same pot. The respondents further indicated the farm size (number of livestock reared), ownership of the herds they reared (hired herder, owner herder, relation of owner) and the motive for animal reared. Information on' membership of social organization and source of farm labour (family members, hired labour) were elicited.

Respondents provided their annual farm income from herding operation in Nigeria naira.

Respondents were requested to indicate on a four point Likert type scale of very great extent (4), great extent (3), some extent (2) and no extent (1) the causes of conflict with crop farmers. Possible causes listed include damage to crops by cattle, blockage of cattle routes with crop farms, pollution of source of water by the pastoralists and others. To identity the challenges of conflict on livestock production by pastoralist, a list of possible challenges of conflict was made available. Respondents were requested to indicate the perceived seriousness of the challenges on a four point Likert type-scale as follows: Very serious (4), serious (3), fairly serious (2), not serious (1). Analysis was conducted using descriptive statistics and factor analysis using principal component method with varimax rotation of Kaiser Normalization. Factor analysis is used mainly to determine some underlying pattern or relationship that exist among variables; discovering a new set of factors; or confirming existing factors as being the true factor(s) (Kleinbaum and Kupper, 1978). The factor loading high under each factor variable (Beta weight) represents a correlation of variables to the identified factors and has the same interpretation as any correlation coefficient. However, only variables with loading of 0.40 and above (10% overlapping variance) (Comrey in Chukwuone et al., 2006) were used in naming factors. Also factors that loaded in more than one places were discarded.

RESULTS AND DISCUSSION

Socio-economic characteristics of respondents

Table 1 shows that Fulani pastoralists were predominantly males (95.8%) with mean age of 39 years. Majority (81.7%) of pastoralists were within active years of economic and productive age. This is probably due to the nature of herding work which requires much physical exertion of energy. The dominance of male pastoralist confirms the labour specialization in which herding is the exclusive role of male members of the family. Traditionally, herding is the sole duty of male members of Fulani pastoralist family. In the Fulani culture, labour is specialized, that is, men's work differs from that of women and that of the adult differs from that of the children. Traditionally, female household members are solely charged with culinary responsibilities, weaving and mat making, sales of dairy products and care of disabled animals. Most (80.3%) of the pastoralists were married with average household size of 11 persons. The large family size could be attributed to the teaching of the Islamic faith which permits four wives per adult man and dependence on their biological children for herding operation. A greater proportion (58.0%) of the pastoralists had no western formal education as against 66.2% that had Islamic education. This could affect the attitude and conflict behavior of respondents due to differences in belief and value system.

The majority (81.7%) of Fulani pastoralists owned between 100 and 300 cattle. The average herd size of cattle was 240. Relatively, the herds' size of the pastoralists is large. It is not surprising because Kogi State is naturally endowed with large expanses of unfarmed lands of savanna grassland attractive to

Table 1. Percentage distribution of respondents by socio-economic characteristics of pastoralists.

Socio economic variable	Percentage	Mean
Sex		
Male	95.8	
Female	4.2	
Age		
Below 21	11.3	
21 - 30	15.5	
31 - 40	36.6	38.9 yrs
41 - 50	18.3	
51 - 60	12.7	
61 - 70	4.2	
Above 70	1.4	
Marital status		
Married	80.3	
Widowed	1.4	
Single	18..3	
Educational levels		
No formal education	58.0	
Non formal Islamic education	33.8	
First school leaving certificate	42.0	
Senior school leaving certificate	1.4	
BSC/HND	-	
Formal Islamic education	66.2	
Household size		
Below 10	46.5	
10-19	33.8	
20-29	12.7	11.4
30-39	6.0	
Herd size		
Below100	7.0	
101-200	59.2	239.6
201-300	15.5	
301-400	4.2	
401-500	7.0	
Above500	702	
Ownership of cattle		
Herders	50	
Hired workers	20	
Children	30	
Production motive		
Symbol status	80.8	
Income	19.2	
Membership of organization		
Fulani Youth Association of Nigeria	16.9	
Mayeiti Allah cattle breeders Association	83.1	
Income/year (Naira)		
Below300,000	43.7	
300,001-400,000	18.3	700,000.00
400,001-500,000	8.5	
500,001-600,000	7.0	
Above600,000	22. 5	

Table 2. Conflict factors as perceived by pastoralists.

Conflict factors	Socio-economic	Security	Production system	Institutional
Sexual harassment	-0.12	**0.82**	0.13	0.23
Blocking water source	-0.06	0.57	0.51	-.04
Farming across cattle routes	-0.01	0.09	**0.74**	-0.06
Farming in fadama areas	-0.33	**-0.63**	0.37	-0.11
Cultural differences	-**0.49**	-0.00	-0.19	0.37
Proximity	0.76	0.40	0.05	-0.05
Language barrier	-**0.79**	-0.36	-0.10	0.06
Limited grazing resources	**0.63**	-0.24	-0.19	0.23
Farm fragmentation	**-0.56**	-0.20	0.02	0.28
Farmlands left fallow	0.075	0.005	**0.78**	0.00
Commercialization of crop residue	-0.47	-0.07	0.54	0.28
Declining influence traditional leaders	0.66	0.46	0.09	0.03
Population growth	**-0.61**	-0.07	0.20	0.08
Burning of rangeland	**0.75**	0.03	0.10	-0.12
Claim of citizenship	-0.20	-0.06	-0.08	**0.73**
Claim of land ownership	-0.35	-0.16	-0.16	-**0.60**
Farmers beat up herdsmen	**0.69**	0.00	-0.22	-0.04
Attack of Fulani women	0.05	**0.89**	0.09	-0.14
Setting traps for herds by farmers	-0.34	-**0.51**	0.07	0.34

nomadic pastoralists. It has a large expanse of fadama lowlands in the river basins and stretches of tropical forest in the south and western belt of the state suitable for production livestock. This attracts herders to the state, encourages population growth of herds and resultant competition for resources. Consequently, proximity to farming communities and the mere sight of such large number of cattle in the farms can be frightening, unwelcoming and may be a source of conflict. Fifty percent of herders owned cattle, while 30.0 and 20.0% of cattle were owned by hired workers and children, respectively. This suggests that the large stock of herds usually seen grazing fields do not in most cases belong to a single owner but an aggregation of family stock grazed by either the household heads, their children or hired workers. This system of herding also aggravates the problem of conflicts that results from straying animals abandoned by poorly remunerated herdsmen.

The majority (80.8%) of Fulani herdsmen claimed that their herding motive was as a symbol status and for commercial purposes and 19.2%. claimed it was for income purpose only. Culturally, ownership of cattle among Fulani pastoralists is a symbol of social status. The greater number of cattle owned, the higher the social status of an individual in a Fulani society. All (100.0%) Fulani herdsmen were members of organizations; while 83.1% belonged to Mayeiti Allah Cattle Breeders' Association (MACBA), 16.9% belonged to Fulani Youth Association of Nigeria (FYAN). The respondents have social affiliation within their societies. This could be a useful tool for conflict management, if effectively mobilized and institutionally supported. Moreover, membership of social organizations in rural areas is of immense value if such organizations could help members accomplish tasks an individual cannot achieve alone (Ekong, 2010). For instance, Miyetti Allah cattle breeders' association helps to improve herding goals of Fulani nomads in Nigeria beyond the level of an individual herdsman.

Herdsmen-farmer conflict factors

Table 2 shows Varimax rotatory factor matrix of conflict factors as perceived by pastoralists. Four factors were extracted namely socio-economic, security, production practices and institutional factors.

Socio-economic factor

Issues that correlated with socio-economic factors included burning of range land (0.75), farmers beaten up (0.69), limited grazing resources (0.63), farm fragmentation (0.56), population growth (-0.61), language barrier (-0.79) and cultural differences (-0.49). It is surprising that cultural differences, language barrier and population growth have inverse relationship with the latent factor, that is in opposition, perhaps due to low perception of these factors as causes of conflict by the respondents. They constitute key structural factors enumerated by Moritz (2010) as underlying causes of pastoralists-farmers conflict; which may not be perceived at facial look. In practice, increase in cultural and language divides among disputants worsen the problems of communication and acceptance; and subsequently, exacerbates potential for conflict. Also growth in population of human and livestock increases pressure on land and competition over resources use.

Similarly, limited grazing resources, farm fragmentation, burning of rangeland and attack of herdsmen by crop farmers showed positive relationships and significant contributions to the causal factor. For instance, farm fragmentation, which characterized most rural production systems could impede easy control of herds by herdsmen. Burning of rangeland often used by pastoralists as a quick option for access to fresh pasture during the dry season intensifies conflict, particularly when fires spread into neigbouring farms causing crop destruction and damage of farm land. Sometimes herdsmen are attacked by youth from farming communities due to refusal to comply with agreements, disregard for traditional institutions, and persistent destruction of human life and property. Moreover, limited grazing lands often associated with intensification of farming activities and population growth results to uncontrolled herding by pastoralists. Animals stray into crop farms leading to destruction of crops and farm land. Gefu and Kolawole (2002), observes that arable crop farmers have not only intensified the use of land but have also been exploring other frontiers for farming like expansion of cultivated lands and use of irrigation for dry season production. Farmlands that used to be fallowed for natural rejuvenation of the soil are fast disappearing. Sidi (2009), opines that as arable land are getting scarcer, while demand for grazing areas is on the increase, the unrestricted movement of herders and their cattle would eventually be seen as a threat to crop farmers

Security factor

Conflicts are caused by threats to life and property. Factors that loaded high were sexual harassment (0.82), attack of Fulani women (0.89), setting traps across cattle routes (0.51) and farming in fadama areas (-0.63). Insecurity of household members and animals of pastoralists were largely associated with widespread conflicts in most rural communities in Nigeria (Olabode and Ajibade, 2010; Okoli and Atelhe, 2014). The lives of pastoralists revolve around their livestock and so they could resist any attempt to jeopardize their life or health through animal rustling or traps along cattle routes. Traditionally, *fadama* land in Nigeria is used for rainy season crop production and left fallow for most part of the dry season for livestock grazing. Most herders found relief in pasturing their animals in the uncultivated wetlands during the dry season, but with the advent of the dry season irrigation projects, herders have been denied access to this dry season grazing resource (Gefu and Kolawole, 2002) and attempts by herders to graze livestock in such land have resulted to fierce conflict. However, herdsmen knowledge of farms in the *fadama* areas and avoidance of traps set on cattle routes could minimize conflict with crop farmers. Moral indiscipline of crop farmers toward Fulani women could present an increased potential for conflict with herdsmen.

Production practice

Factors that loaded high under production practices of farmers were fallow farmlands (0.78) and farming across cattle routes (0.74). The presence of farms on cattle routes and fallow farmland increase potential for conflict between crop famers and herdsmen. This could be traced to the collapse of the agreement in the 1970s over the use of agreed migration routes in the country, when farmers felt they own land across which cattle move in search of pasture (Blench, 2010). Sometimes, farmers are attracted by the high quantity of manure to farms across cattle routes. Thus, as cattle migrate southward, they wander into the newly created farms resulting in conflict between farmers and herders. Moreover for an average Fulani-herdsman, pastoralism is a way of living, which is reckoned with as a mark of common heritage. In effect, any threat to his herds amounts to a threat, not only to his survival but also to his common destiny (Okoli and Atelhe, 2014). This creates a high risk of conflict between the two resource users. Sometimes, farmers leave their land fallow to allow for revitalization of soil nutrient particularly where there are patches of lands and this serves as grazing land for pastoralists. Consequently farm lands are exposed to destruction by animal hooves and degradation over time. This could spur conflict behaviour and aggravates conflict situation as farmers contend with pastoralists to protect their land.

Institutional factors

This include factors that are related to claim of citizenship (0.73) ownership of land (-0.60). The problems of land ownership and citizenship appear to be critical and persistent issues in herdsmen-farmers conflict in Nigeria. Fulani herdsmen believe that nobody owns land (land is God’s gift) and so, they see land as common property and with this conception of land ownership, they violet avenues that could engender mutual coexistence with farming communities (personal communication). In most communities in Nigeria, herders are given temporary settlement right, which they often over stay and subsequently demand equal right of tenure and exploitation. This eventually results to conflict in almost all states of the federation. Land is the resource base of

Table 3. Challenges of conflict in livestock production.

Challenges	social	Displacement	Economic
Break down of law and order	-0.31	0.34	-0.11
Unsafe grazing fields	-0.38	**-0.46**	0.18
Poor animal health	**0.68**	-0.07	-0.39
Cattle abandonment	-0.28	**0.75**	0.21
Displacement	0.05	**0.69**	0.16
Insufficient food for livestock	0.34	-0.31	-0.04
Insufficient beef supply	0.21	-0.02	-**0.60**
Over concentration of cattle	-0.25	-0.08	0.03
Outbreak of hunger/diseases	.0.13	0.05	-0.30
Loss of lives	0.69	0.09	0.44
Loss of income	-0.39	**-0.49**	-0.06
Loss of animal	0.20	-0.04	**0.74**
Migration of herders	0.44	0.58	0.07
Forced ejection	-0.06	**0.70**	-0.19
Poisoning of livestock water source	0.06	0.47	0.50
Destruction of lives and property	0.23	0.33	**0.75**
Increased number of widows and orphans	0.12	0.28	0.15
Destruction of mutual trust	**0.76**	-0.03	0.04
Proliferation of fire arms	**0.74**	0.06	0.00

pastoralists and according to Sandford and Habtu (2000) are used with specific access mechanism and tenureship. Tenuche and Ifatimehin (2009) reported that it is a source of major conflict in Benue State, accounting for about 30% conflicts in the state. The problem of insecure land tenure system can further hampers equitable resource management which could lead to conflict.

Challenges of herdsmen-farmers' conflict in livestock production

The principal component analysis identified three major challenges of herdsmen-farmers' conflict to livestock production. They included insecurity of life, displacement and economic factors (Table 3).

Social challenge

The results show that conflict between pastoralists and farming communities resulted to destruction of mutual trust (0.76), proliferation of small arms (0.74), poor animal health (0.68) and migration of herders (0.44). In the past, herdsmen and crop farmers had an interdependent relationship based on the local exchange of dairy products for grain, cereal residues and fertilization of farmland through animal dung and the periodic sale of animals. Mwamfupe (2015) opines that it is characterized by both conflict and complementarity and is actually two faces of the same coin. However, when conflict between the two resource users occurs, it affects the mutual trust that might have existed before the outbreak of conflict, causing either side to view the other with contempt and some level of mistrust. Conflict breaks down symbiotic relationship and harmony required for peaceful co-existence for enhanced crop and livestock production. A good number of herdsmen owned firearms as a means of self defense and are always battle ready. This confirms a new dimension of militancy introduced into farmer-herder conflict (Abbas, 2009), which is associated with the involvement of aggressive Udawa and Bokoloji pastoralists from northern Borno. This can result to loss of human and animal lives leading to frustration and decline in productivity of pastoralists. Furthermore, conflict increases health risk for pastoralists and their livestock because of ejection and forced migration of herdsmen, whose movement is determined by availability of veterinary services, subdued tsetse fly environment and other productive resources. Also movement close to dense population adversely affects their survival because it results in scarcity of grazing land and over concentration of cattle in an area.

Thus, the pastoralists are often considered more vulnerable in conflict situations than crop farmers in an environment of absence or poor access to veterinary services and health facilities resulting in the loss of lives and poor animal health. Overall, conflict negatively impacts on the social, human and physical livelihood assets of pastoralists. It leads to loss of productive resources, affinity and common voice critical for the wellbeing and survival of pastoralists.

Pastoralists' displacement

Conflict largely affects movement and migration of herdsmen and their livestock. Factors that loaded under this were cattle abandonment (0.75), forced ejection (0.70), displacement of herdsmen (0.69), loss of income (-0.49) and unsafe grazing field (-0.46). Conflict in agrarian communities negatively affects access to grazing fields, lives and property which may lead to abandonment of cattle and relocation of herdsmen. Forced ejection of herdsmen could be as a result of uncompensated damages done in farming communities where they were previously accepted before outbreak of conflict. Cumulatively, these have ripple effects both on the productive resources, productivity of livestock, and income, food, nutrition and health security of pastoralists. Displaced herdsmen often loose requisite livelihood assets ranging from pasture land, animals/foundation stock, labour, health facilities, market, banks, and group alliance. Also livelihood decision is disrupted and made more vulnerable to conflict and other environmental factors. It could further precipitate to over concentration of cattle in other locations and consequently, increase the area of the conflict. According to Zincita (2011), the negative effects of conflict are an increase in stress for the disputants, decrease in production, degradation of relationship, worsening cooperation, and increase in restricted areas and possibilities of violent conflict. The resultant effects may be breakdown of social, economic and political structure of farming communities.

Economic factors

The variables that had significant influence were wanton destruction of lives and property (0.75), loss of animals (0.74), and insufficient beef supply (-0.60). Conflict leads to wanton destruction of properties, human and animal lives which impacts on availability and access to sufficient beef, income and wellbeing of herdsmen. The result confirms Gbaka (2014) who observed that significant loss of lives and property has occurred in many parts of Nigeria including Katsina, Plateau, Taraba, Kwara, Nasarawa,Adamawa, Gombe, Yobe and Kebbi States. In the guinea Savannah area of Kwara State, scholars also reported that out of about 150 households interviewed, 22 reported losses of livestock, while eight households reported loss of human lives due to pastoralist-farmers conflicts (Olabode and Ajibade, 2010: Fiki and Lee, 2004). Pastoralists experience huge economic losses from incessant conflicts with farming communities which subsequently affects investment in production. In addition to loss of properties, life and animals, often much income is expended in the payment of compensation and arbitration of cases. Invariably, the livelihood capabilities and productivity of livestock are undermined and compromised.

Conclusion

Conflict between pastoralist and farmers in agrarian communities presents a formidable challenge to livestock production in Nigeria. It is associated with both structural issues like population, cultural, political and ethno-religious differences as well as unproductive conflict behaviors and struggle for livelihood survival by the disputants. The results points to problems of incompatibility of livelihood strategies, competition for access and use of natural resources such as land and water. Pastoralist-farmers' conflict has production and economic consequences for herding. Pastoralist's assets both in terms of human, physical, social, economic are affected, hence productivity and sustainability of the sector will be compromised. Therefore, we recommend that all stakeholders (government, non-governmental organizations, extension agencies, rural institutions among others) should intensify efforts to build cooperative and peaceful coexistence between farmers and pastoralists through public enlightenment, education and campaign in agrarian communities. Government and NGOs should promptly intervene with aids/compensation to reduce vulnerability, persistence and further spread of conflict of pastoralist-farmer conflict in communities. Also, the need to enforce policies that ensure strict compliance to grazing reserve and migration routes is an imperative for sustainable management of herdsmen-farmers' conflict in agrarian communities.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

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Viability of the use of grass in the cultivation of the medicinal mushroom *Ganoderma lucidum*

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The objective of this work was to evaluate the use of ten types of grasses as base substrate for the cultivation of strain GLM-10/02 of *Ganoderma lucidum*, considering the chemical characterization of the substrates, the biological efficiency (BE), the quantification of fresh and dry basidiomata and the number of basidiomata as evaluation criteria. Ten treatments were outlined, made up with napier or elephant grass (*Pennisetum purpureum*), marandu grass (*Brachiaria brizantha* cv. Marandu), aruana grass (*Panicum maximum* cv. Aruana), massai grass (*Panicum maximum* cv. Massai), mombaça grass (*Panicum maximum* cv. Mombaça), brachiaria grass (*Brachiaria decumbens* cv. Basilisk), humidícola (*Brachiaria humidicola* cv. humidicola), xaraés grass (*B. brizantha* cv. Xaraés), tifton (*Cynodon* species cv. Tifton 85), piatã grass (*B. brizantha* cv. BRS Piatã) and a control treatment based on eucalyptus sawdust. All the treatments had 80% of grass, 18% of wheat bran and 2% of limestone, with humidity adjusted to 60%. The treatments based on *B. brizantha* cv. Aruana (aruana) and *Cynodon* spp. cv. Tifton 85 (tifton) showed the best results, with 22.9 and 25% of BE, respectively. These data showed that not all grasses used in the experiment have the same fungal biomass conversion and it was concluded that *B. brizantha* cv. Aruana (aruana) and *Cynodon* spp. cv. tifton 85 (tifton) were the most indicated grasses for the cultivation of *G. lucidum*.

Key words: Productivity, biological efficiency, substrates, fungi.

INTRODUCTION

The appropriate selection of the substrate is very important for the success of every kind of mushroom production. Agro-industrial residues, such as grasses, coffee pulp, cereals bran, crushed sugar cane, processed fruit peels, potato, cereals flour, cassava and others, are widely used substrates in these processes (Alquati et al., 2016; Carvalho et al., 2015; Roy et al., 2015; Erkel, 2009). The material with potential for sale in the agricultural production corresponds to 5%, while the remaining has great potential for biotransformation and

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Table 1. Experimental treatments tested in this experiment.

Treatment	Type of straws (popular name)
1	*Pennisetum purpureum* (napier or elephant grass)
2	*Brachiaria brizantha* cv. Marandu (marandu)
3	*Brachiaria brizantha* cv. Aruana (aruana)
4	*Panicum maximum* cv. Massai (massai)
5	*Panicum maximum* cv. Mombaça (mombaça)
6	*Brachiaria Decumbens* cv. Basilisk (brachiaria)
7	*Brachiaria humidicola* cv. Humidícola (humidícola)
8	*Brachiaria brizantha* cv. Xaraés (xaraés)
9	*Cynodon* spp. cv. tifton 85 (tifton 85 or Bermuda grass)
10	*Brachiaria brizantha* cv. Piatã (piatã)
11 (Control)	*Eucallyptus* spp. (eucalyptus sawdust)

All the substrates were added with 18% of wheat bran and 2% of limestone (dry weight). Humidity was adjusted to 60%.

bioconversion into organic matter that can be applied to the soil and serve as animal food, or even used for the production of fungi and bacterial protein biomass.

The *Ganoderma* species fungi are called Reish by the Chinese and Ling Zi by the Japanese. In face of their innumerous properties, they are mainly known for their medicinal power (Lin, 2009).

In China, their cultivation was originally carried out in logs and sawdust from tree species (*Pinus* species, *Eucalyptus* species and others). This type of substrate has gradually been replaced by several grass species, for ecological reasons and preservation of native species (Lin, 2009). Moreover, the conversion of sun energy in grass species is 6 to 8 times higher than in the tree species used in conventional cultivation. Fungi grown on grasses have higher productivity than those grown in sawdust, possibly being 30% higher. Also, the nutritional quality of the mushrooms is equal or higher (Zhanxi and Zhanhua, 2001).

Although, the production of mushrooms in Brazil is continuously expanding due to the findings of their medicinal and cooking properties; it still needs the development of a suitable cultivation technology to match the conditions of the country. For many years, the technology used was adapted from developed countries which have different weather conditions and raw materials (Dias, 2010).

The *Ganoderma lucidum* mushroom is classified as lignocellulosic because it develops naturally in substrates rich in lignin and cellulose (Erkel, 2009). Consequently, it has an affinity with a wide variety of residues, including grass species. However, *G. lucidum* is still little grown in Brazil and the most used substrate is based on eucalyptus sawdust.

The grass species grown in pastures are potential high-quality substrates for mushroom cultivation. Limited data and reference texts are available about the use of grass species for the cultivation of *G. lucidum*. It is necessary to compare the response of several mushroom strains in several types of straws in terms of productivity and quality of the mushrooms obtained. Weather conditions and the level of the cultivation technology should also be part of these studies.

The replacement of traditional wood based substrates (logs and sawdust) by grasses, cereal straws and other agricultural residues might dispense the nitrogen supplementation and reduce the production cost. An investigation made by Zhanxi and Zhanhua (2001) revealed that some grass species can replace sawdust and partially rice bran in the cultivation of *Pleurotus ostreatus*. Dias et al. (2003) reported that the bean husk for the cultivation of *Pleurotus sajor-caju* dispenses nitrogen supplementation. In addition to the high productivity and easy adaptation in Brazil, the protein, nitrogen, fat, phosphorus, potassium and magnesium contents in grasses are higher than those in sawdust (Zhanxi and Zhanhua, 2001).

The aforementioned advantages of the *G. lucidum* cultivation have increasingly attracted interest by investors and rural producers as an extra alternative to the family income, as well as an environmentally friendly option in the use of residues. Thus, the objective of the present research was to evaluate the viability of the use of different types of grass species in the cultivation of the medicinal mushroom *G. lucidum*.

MATERIALS AND METHODS

The experiment was conducted in the Mushrooms Module, at the School of Agronomic Sciences, Universidade Estadual Paulista (UNESP), in the city of Botucatu, state of São Paulo.

The spawn of strain GLM-10/02 of *G. lucidum* was obtained from the Fungi Herbarium of the Mushrooms Module, FCA/UNESP and was wrapped in High Density Polyethylene (HDPE) packs containing the substrates previously prepared (Table 1) and sterilized in an autoclave at a temperature of 121°C for 4 h.

After being sterilized and under room temperature, the packages were taken to a laboratory with a laminar flow chamber, in order to inoculate the Spawn of *G. lucidum*. Then, they were stored under the controlled temperature of 25°C for two weeks, until they reached the ideal point (total colonization of the grains – spawn) to be inoculated in the treatments with the grass species.

The second step consists of obtaining the grass for the production of the substrates. The grass species were obtained from the experimental beds of the Department of Animal Improvement and Nutrition of the School of Veterinary Medicine and Animal Science (FMVZ) of UNESP with the use of a grass cutting machine.

After being cut, the grass species were organized and identified with their respective names in common raffia bags and stored in an open sides and covered environment (shed) to prevent rainwater from hindering the drying process, which took two weeks. Later, the packages were taken to a masonry stove set to a temperature of 40°C, allowing an homogeneous drying.

Right after drying, the straws were ground with a conventional grinder to reach the particle size required for the development of the fungus. The ground material was weighed with the following proportions to be wrapped in HDPE packs before passing through the sterilization process. The formulations of the experimental treatments (composition of the substrates) followed the same procedure for all treatments, made up with (dry weight) 80% of grass, 2% of limestone and 18% of wheat bran. Water was added until substrate was moistened to 60%.

The experimental design was totally randomized, in factorial scheme, corresponding to the 10 types of cultivation substrates based on different grass species and a control (eucalyptus sawdust) (Table 1), with 6 repetitions each (700 g substrate block), totaling 66 experimental units.

Next, the material was homogenized in a concrete-mixer used in the building industry, pressed and had PVC pipe cork and cotton placed on the top of the package to allow gas exchange and the development of *G. lucidum*. All packages were submitted to the sterilization process at 121°C for 4 h so that only the desired fungus was developed in the production, thus preventing the contamination of the packages.

The inoculation of the packages with the strain GLM-10/02 of *G. lucidum* was carried out after they were cooled to room temperature in the laboratory, by using a laminar air flow chamber, under appropriate aseptic conditions, thus avoiding contamination by other microorganisms.

After this procedure, they were taken to a climatized room and were kept at the temperature of 25°C until the complete colonization of the substrates, which lasted for approximately two weeks. Once colonized, the packages were moved to a rustic greenhouse, made with a bamboo structure and covered with transparent plastic, installed on a farm named Estância Saad (Saad Ranch), in the city of Botucatu, São Paulo. The packages were placed in the greenhouse and randomly arranged. At this time, the cotton plugs were removed.

The average temperature in the greenhouse was maintained at 25 ± 5°C and the relative humidity at 60 to 85%, with irrigation whenever the ground floor was dry. After 30 days, the mushrooms began to develop.

After 60 days, the color of the mushrooms was observed by their different tones and texture so as to quantify their maturation and development as parameters in the harvest decision. The harvest procedure was quite simple, by just twisting and pulling them from the packages. All the mushrooms harvested were weighed with a precision scale and placed in plastic containers identified according to the treatment.

In this step, the number of basidiomata present in each treatment was quantified, as well as the mass of the fresh basidiomata. The productivity of each treatment was expressed by means of the biological efficiency (BE) (Das and Mukherjee, 2007; Tisdale et al., 2006) and is described according to Equation 1:

$$BE\ (\%) = \text{Total fresh mass of mushrooms (g)} / \text{Dry mass of the initial substrate (g)} \times 100 \quad (1)$$

Chemical characterization of the substrates

The collection of the samples of the cultivation substrates was made soon after the substrate sterilization process (initial substrate) and the end of the cultivation cycle (exhausted substrate). Two samples of the different types of substrates were separated and sent to the laboratory for chemical analysis of fertilizers and correctives at the Department of Natural Resources, Soil Science, FCA/UNESP for their chemical characterization (N, organic matter, C, C/N, humidity and pH), according to Lanarv's methodology (1988).

Statistical analysis

The data obtained were submitted to variance analysis and averages were compared by the Tukey's test (5%) (Snedecor and Cochran, 1972) using the SISVAR 4.2 software developed by the Department of Exact Sciences of the Federal University of Lavras (UFLA).

RESULTS AND DISCUSSION

The use of grass species for the preparation of substrates in the cultivation of *G. lucidum* is a promising alternative, especially in our country, which has a large amount of species and cultivars that can be used as a raw material in the formulation of substrates. Vieira (2012) highlights that grass species have a solar energy conversion factor 6 to 8 times higher than the tree species, which are frequently used as sawdust for the conventional cultivation of mushrooms. According to Zhanxi and Zhanhua (2001), the fungi cultivated in grass species have a higher productivity; possibly being 30% higher than in the substrates produced using sawdust composts.

The results of the chemical analysis of substrates were evaluated in the experiments, such as nitrogen, organic matter, carbon, C/N ratio, humidity, pH prior to the inoculation with *G. lucidum* (initial substrate) and at the end of the cultivation cycle (final or exhausted substrate). The mass of fresh basidiomata (MFB), the number of basidiomata (BN) and their BE were also evaluated.

Chemical analysis

In order to reach a favorable C/N ratio for the production of mushrooms, the supplementation of these substrates with a nitrogen source has been commonly adopted, especially wheat bran. Philippoussis et al. (2007) reported that the carbon and nitrogen content of the substrate influences the precocity of “fruiting” and productivity. Boyle (1998) reports that the degradation of lignin is also important for the growth, since it can make the access to nitrogen contained in the wood components

Table 2. Chemical analysis before the inoculation of *Ganoderma lucidum* (initial substrate).

Treatment	N%	MO%	C%	C/N	Humidity (%)	pH
Pennisetum purpureum (napier or elephant grass)	0.4	32	18	45/1	56	5.7
Brachiaria brizantha cv. Marandu (marandu)	0.5	32	18	36/1	57	6
Brachiaria brizantha cv. Aruana (aruana)	0.7	34	19	27/1	55	5.7
Panicum maximum cv. Massai (massai)	0.7	33	18	26/1	56	5.9
Panicum maximum cv. Mombaça (mombaça)	0.6	35	19	32/1	54	6
Brachiaria Decumbens cv. Basilisk (brachiaria)	0.6	35	19	32/1	57	6.3
Brachiaria humidicola cv. Humidícola (humidícola)	0.7	40	22	31/1	50	6
Brachiaria brizantha cv. Xaraés (xaraés)	0.6	35	19	32/1	56	5.8
Cynodon spp. cv. tifton 85 (tifton 85 or bermuda grass)	0.6	35	19	32/1	56	5.9
Brachiaria brizantha cv. Piatã (piatã)	0.5	36	20	40/1	55	5.8
Eucallyptus spp. (eucalyptus sawdust)	0.3	35	19	63/1	60	6.4

Table 3. Chemical analysis of the final substrate (exhausted).

Treatment	N%	MO%	C%	C/N	Humidity (%)	pH
Pennisetum purpureum (napier or elephant grass)	0.5	30	17	34/1	57	4.6
Brachiaria brizantha cv. Marandu (marandu)	0.6	34	19	32/1	57	6.5
Brachiaria brizantha cv. Aruana (aruana)	0.5	32	18	36/1	57	7.5
Panicum maximum cv. Massai (massai)	0.7	26	14	20/1	62	5.2
Panicum maximum cv. Mombaça (mombaça)	0.6	30	17	28/1	61	5.0
Brachiaria Decumbens cv. Basilisk (brachiaria)	0.6	27	15	25/1	64	5.6
Brachiaria humidicola cv. Humidícola (humidícola)	0.8	36	20	25/1	56	5.6
Brachiaria brizantha cv. Xaraés (xaraés)	0.3	17	9	30/1	78	6.8
Cynodon spp. cv. tifton 85 (tifton 85 or bermuda grass)	0.7	28	16	23/1	64	5.4
Brachiaria brizantha cv. Piatã (piatã)	0.4	25	14	35/1	63	5.9

available for fungi. According to Hsieh and Yang (2004), the *G. lucidum* species requires an optimal C/N ratio of 70/1 to 80/1 for an efficient growth and low production cost. For Gurung et al. (2012), this fungus species requires an optimal pH of 5.0 to 7.0.

The average contents obtained by the chemical analysis of the initial and final substrates are described in Table 2.

An important and relevant characteristic in the C/N ratio occurred in the treatment using eucalyptus sawdust (63/1). Our findings are confirmed by Hsieh and Yang (2004), who reported that *G. lucidum* species requires an optimal C/N ratio of 70/1 to 80/1 for an efficient growth and low production cost.

Treatment with *Brachiaria brizantha* cv. Piatã (piatã grass) suffered the action of other contaminant fungi during the production process and had to be discarded to avoid the contamination of the other treatments. Therefore, the analysis of the exhausted compound could not be performed.

In relation to the C/N ratio of the exhausted compound (Table 3), it was observed that some treatments suffered degradation by the fungus during the production cycle. This is due to the metabolism (mycelial growth) of the fungus, which is considered lignocellulosic (Urben, 2011).

Biological efficiency

The biological efficiency of each treatment represents the conversion of the substrate into biomass for the mushroom development. This index is the most used by researchers because it makes the comparison of the results with the literature easier (Das and Mukherjee, 2007; Tisdale et al., 2006).

Figure 1 presents the percentage of biological efficiency of each treatment. The substrates containing *B. brizantha* cv. Aruana (aruana grass), with 22.9% of BE and *Cynodon* species cv. tifton 85 (tifton 85), with 25%, presented better statistical results in relation to the other substrates, including the traditionally used control with eucalyptus sawdust, with biological efficiency of 4.8%.

Rolin et al. (2014) obtained higher results than the others (BE, 72%) by cultivating *G. lucidum* in substrate based on elephant grass + mango tree sawdust, supplemented with 10% of wheat bran and 10% of

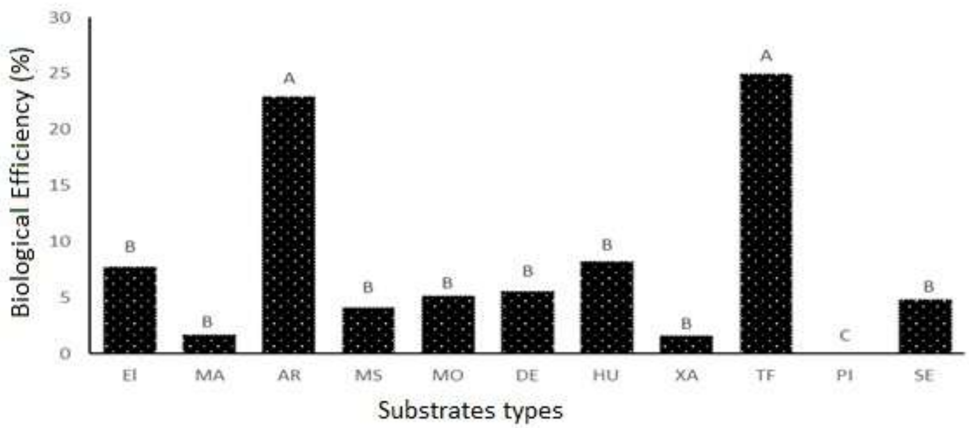

Figure 1. Biological efficiency of strain GLM-10/02 of *Ganoderma lucidum*, cultivated on substrates based on grass species. Averages followed by the same letters do not differ from each other, (Tukey, 5%). CV (%) 67.20. Averages of 6 repetitions. EL: Elephant Grass (napier); MA: Marandu; AR: Aruana; MS: Massai; MO: Mombaça (Colonião); DE: Decumbens; HU: Humidícola; XA: Xaraés; TF: Tifton; PI: Piatã; SE: Eucalyptus Sawdust. All treatments were added with 18% of wheat bran and 2% of limestone. The humidity was adjusted to 60%.

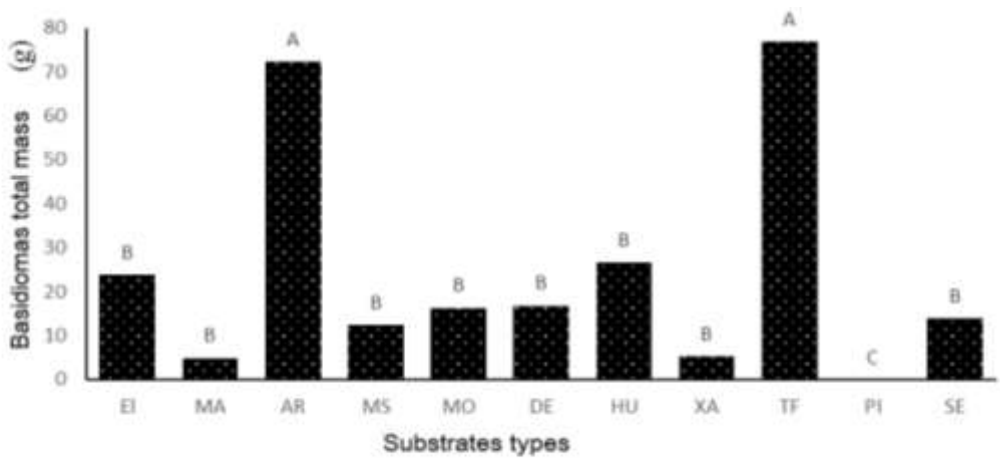

Figure 2. Total mass of the fresh basidiomata from the strain GLM-10/02 of *Ganoderma lucidum*, cultivated in substrates based on grass species. Averages followed by the same letters do not differ from each other, (Tukey =, 5%). CV (%) 69.07. Averages of 6 repetitions. Subtitle: EL: Elephant grass (napier); MA: Marandu; AR: Aruana; MS: Massai; MO: Mombaça; DE: Decumbens; HU: Humidícola; XA: Xaraés; TF: Tifton; PI: Piatã; SE: Eucalyptus sawdust. All treatments were added with 18% of wheat bran and 2% of limestone. The humidity was adjusted to 60%.

crushed sugar cane.

The piatã grass obtained BE of 0% because all the treatments were contaminated.

Total mass of the fresh basidiomata

The total mass of the fresh basidiomata from each treatment was obtained by means of the harvest carried out during the experiment, in a total of 90 days of production (Figure 2).

The total mass varied from 76.9 g (Tifton 85) to 72.2 g (Aruana), showing that both types of substrates have a great lignocellulosic potential for the conversion of fungal biomass for the mushroom formation.

Number of basidiomata

The number of basidiomata is the total mushrooms produced by each treatment during the experiment. The sum of the basidiomata corresponds to the harvest of the *G. lucidum* production (Figure 3).

The substrates that provided the highest amounts of

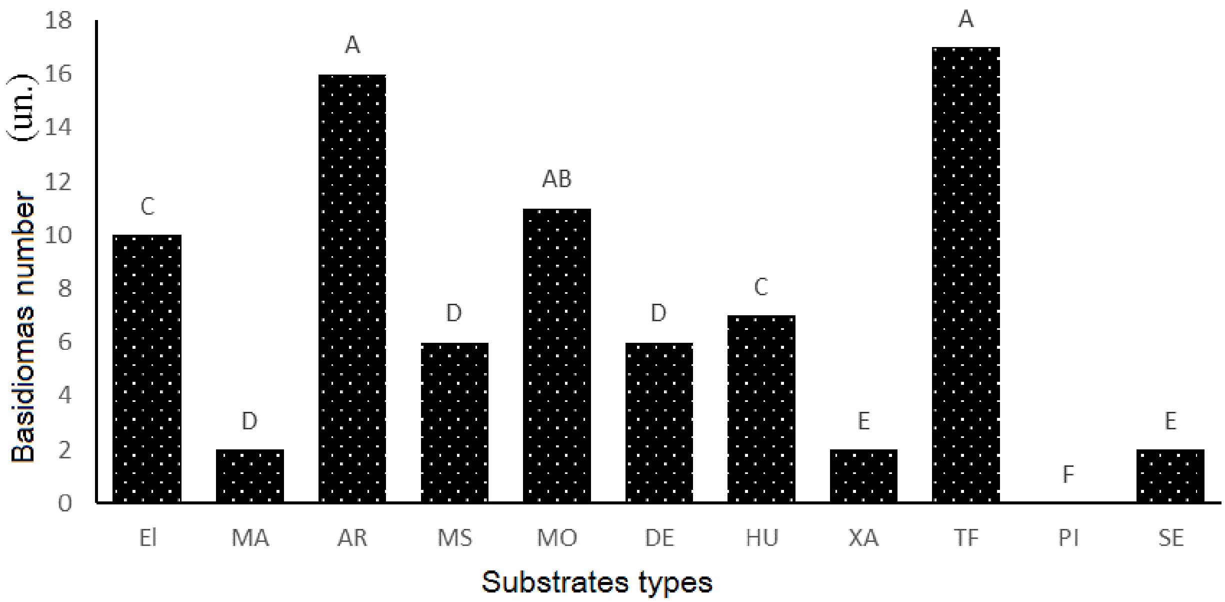

Figure 3. Total number of Basiodiomata from the strain GLM-10/02 of *Ganoderma lucidum*, cultivated in substrates based on grass species. Averages followed by the same letters do not differ from each other, (Tukey =, 5%). CV (%) 58.10. Average of 6 repetitions. EL: Elephant grass (napier); MA: Marandu; AR: Aruana; MS: Massai; MO: Mombaça; DE: Decumbens; HU: Humidícola; XA: Xaraés; TF: Tifton; PI: Piatã; SE: Eucalyptus sawdust. All treatments were added with 18% of wheat bran and 2% of limestone. The humidity was adjusted to 60%.

basidiomata were the treatments based on Aruana and Tifton 85 grass species, with averages of 16 to 17 units per treatment, showing that the choice of the appropriate substrate is fundamental for the mushroom formation and its biological efficiency. The substrate based on piatã grass was contaminated by another fungus and had to be discarded.

Conclusion

The *B. brizantha* cv. Aruana (aruana) and the *Cynodon* spp. cv. Tifton 85 (tifton 85) grass species were the most suitable for the cultivation of *G. lucidum*.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Does the quality of *Luehea divaricata* seedlings in the nursery correspond to their behavior in the field?

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The species, *Luehea divaricata* offers great ecological and timber potential in addition to a wide geographic distribution, although there are few studies comparing seedling production in the nursery with its development in the field. Therefore, this research aimed to evaluate the performance of *L. divaricata* seedlings produced in different substrates in the nursery, as well as verify if the results obtained influence survival and growth after planting in the field. The seedlings were produced with four different substrate formulations (T1: 100% peat-based commercial substrate (Peat); T2: 80% peat and 20% carbonized rice husk (CRH); T3: 60% peat and 40% CRH; T4: 40% peat and 60% CRH). In the nurseries, at 202 days after sowing, the height, stem base diameter, aerial dry mass, root dry mass, total dry mass and Dickson quality index were evaluated. After the seedlings were planted in the field, their survival, height growth and stem base diameter were monitored. *L. divaricata* seedlings produced with up to 40% CRH mixed with peat-based commercial substrate can present adequate growth in the field, although improved performance may occur with even 20% CRH. It should be noted that the growth response of *L. divaricata* seedlings in the nursery is more efficient when associated with the performance of the seedlings in the field.

Key words: Native species, carbonized rice husk, initial growth after planting, substrate.

INTRODUCTION

The growing demand for forest seedlings for various purposes makes the production of healthy and well-developed seedlings increasingly necessary. The quality of the seedlings is of fundamental importance and is linked to the success of reforestation (Lima et al., 2014; Navroski et al., 2015). Therefore, it is important to establish a quality standard for seedlings of different species or groups, for adequate growth and survival in

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the field.

One of the important factors that influences the development of seedlings in nurseries is the composition of the substrate and proportion of components (Filho et al., 2015), which is directly related to seedling vigor at the time of sowing and consequently in post-planting. This influence may be associated with porosity, which is directly linked to the water-holding capacity (aeration space and easily available water) and availability of nutrients to the plant. In addition to the physical and chemical characteristics of the substrate, economic factors (low cost and availability) and ease of management should be considered in the choice of this input (Gasparin et al., 2014).

Many studies have addressed the use of inputs and suitable techniques for the production of seedlings in the nursery (Mesquita et al., 2011; Kratz et al., 2015; Berghetti et al., 2016). However, the behavior of the plants when transferred and planted in the field is not commonly investigated (Abreu et al., 2015). Thus, the results obtained only in the nursery may lead to erroneous conclusions (Vallone et al., 2009).

Luehea divaricata Mart. et Zucc belongs to the family Malvaceae and features wide geographical distribution, including Brazil, Uruguay, Argentina, Paraguay (USDA, 2015) and Bolivia (Tropic, 2015). This species is classified as a pioneer, with fast growth and economic potential, especially for the furniture industry, and it is eco-friendly, since it is recommended for mixed reforestation of degraded areas and permanent preservation (Carvalho, 2003).

Thus, this study aimed to evaluate the development of *L. divaricata* seedlings produced in different substrates in the nursery, as well as to verify whether the responses obtained in the nursery correspond to the survival rate and initial growth of the seedlings in the field.

MATERIALS AND METHODS

Seedling production (Experiment 1)

The fruits were collected from eight trees in a forest fragment (29°42'02" South and 53°47'12" West), in the municipality of Santa Maria, Rio Grande do Sul, Brazil. After processing the fruits and extracting the seeds, the seeds were stored for four months in Kraft paper bags in a cold chamber at a temperature of ±8°C and relative humidity of 80%.

The seedlings were produced in the forest nursery of the Federal University of Santa Maria (29°43' S and 53°43' W). Sowing was performed in polypropylene conical tubes with 110 cm^3 of capacity. The substrates used for production of seedlings were composed of different proportions of peat-based commercial substratum (peat) Carolina Soil® and carbonized rice husk (CRH), with treatments being characterized as T1-100% peat, T2-80% peat and 20% CRH, T3-60% peat and 40% CRH and T4-40% peat and 60% CRH. Controlled release fertilizer (NPK 15:09:12) was used in the base fertilizer at a dosage of 6.0 g L^{-1}.

The physical analysis of the substrate was performed at the Substrates Laboratory of the Department of Horticulture and Forestry of the Federal University of Rio Grande do Sul (Table 1). Sowing was carried out with three seeds per container. Sixty days after sowing (DAS), thinning was carried out, leaving just the most central and vigorous seedling. The seedlings were kept in the greenhouse for 82 days and were then then transferred to beds in full sunlight with irrigation depth of 16 mm/day^{-1}, as recommended by Dutra (2012).

The nursery experiment was carried out in a randomized block design with four blocks and four formulations of substrates. The plot was composed of 24 seedlings, and the height (H) and stem diameter (SD) of the nine individuals was evaluated. Out of these, a sample of three plants was taken for destructive analyses (biomass production).

At 202 DAS, seedling height and stem diameter were evaluated with a graduated ruler and digital caliper, respectively. In addition, analysis of aerial dry mass (ADS), root dry mass (RDM) and total dry mass (TDM) was carried out. The aerial part was separated from the root with a pruning shear and the root system washed under running water in order to remove the substrate. The samples were placed in Kraft paper bags and dried in an oven with forced air circulation at 70°C for 72 h. Afterwards, the material was weighed in order to obtain the ADS and RDM, which resulted in the sum of the parts by TDM. The Dickson quality index (DQI) was calculated using TDM (g)/[H (cm)/SD (mm) + ADS (g)/RDM (g)] (Dickson et al., 1960).

Planting in the field (Experiment 2)

Considering the respective treatments, seedlings from Experiment 1 were planted in an area belonging to UFSM (29° 43 ' South Latitude and 53° 44 ' West Longitude), Santa Maria, RS. The climate of the region is Cfa type according to Köppen, with annual average precipitation of 1720 mm and average annual temperature of 19.1, 32 and 9°C, the averages of the hot and cold months, respectively (Heldwein et al., 2009). The area features soil classified as Gray Argisol (Streck et al., 2008) and chemically analyzed at the Soil Analysis Laboratory of UFSM (Table 2). The area was prepared by mowing and sub soiling the planting line followed by opening holes in the dimensions of 5 x 15 cm with 100 g of dolomitic limestone to the hole.

Experiment 2 was conducted in randomized block design with a factorial scheme, with plots subdivided by time (substrate x time). Five blocks were used with nine seedlings per sampling unit, totaling 45 seedlings per treatment and 36 seedlings in each block. The spacing used in the planting was 2 x 2 m.

Seedling survival rate was assessed at 30 and 60 days after planting. On the occasion, fertilization with NPK (5:20:20) was carried out following nutritional recommendations for *Eucalyptus* (SBCS/CQFS, 2004). Two months after planting, concurrent to the second survival rate assessment, the first measurement of height (H) and stem diameter (SD) was conducted, which was maintained at intervals of 60 days during the first 12 months. To assess this, a graduated ruler and digital caliper were used, respectively.

Data were subjected to verification of the assumptions of normality and homogeneity of variance and, afterwards, statistical analysis was performed using the program SISVAR (Ferreira, 2014). Analysis of variance and comparison of means was carried out using the Tukey test and regression analysis at 5% probability of error.

Table 1. Physical characteristics of substrates used in the production of *L. divaricata* Mart. Et Zucc seedlings.

Substrates	AS (%)	EAW (%)	BW (%)	RW (%)
T1	27.75	20.88	3.94	31.8
T2	32.15	18.71	4.00	28.39
T3	36.78	14.42	2.74	29.09
T4	48.16	14.39	2.88	19.18

T1- 100% peat, T2- 80% peat and 20% CRH, T3- 60% peat and 40% CRH and T4- 40% peat and 60% CRH. AS = aeration space; EAW = easily available water; BW = buffering water; RW = remaining water.

Table 2. Chemical analysis of the soil from the planting area, Santa Maria, RS, Brazil.

pH	P*	K	Ca	Mg	Al	MO	Clay	V
H_2O	-----mg.dm^{-3} -----		--------- cmol$_c$.dm^{-3} ---------			-------------- % --------------		
4.8	3.0	0.153	7.9	2.9	3.0	2.8	21	41.6

P: phosphorus *extracted by Mehlich's method I; K: potassium; CA: calcium; Mg: magnesium; Al: aluminum; OM: organic matter; V: base saturation.

Table 3. Characteristics of *L. divaricata* seedlings grown in different substrates in the nursery, 202 days after sowing, Santa Maria, RS, Brazil.

Substrates	H	SD	ADS	RDM	TDM	DQI
T1	33.44^{a}	6.88^{a}	5.14^{ab}	4.82^{a}	9.96^{ab}	2.04^{a}
T2	32.47^{a}	6.82^{a}	5.68^{a}	5.87^{a}	11.55^{a}	1.68^{ab}
T3	29.69^{b}	6.59^{a}	3.67^{bc}	4.26^{ab}	7.93^{bc}	1.48^{b}
T4	21.66^{c}	3.61^{b}	3.04^{c}	2.18^{b}	5.22^{c}	0.70^{c}

H = height (cm); SD = stem diameter (mm); ADS = aerial dry mass (g); RDM = root dry mass (g); TDM = total dry mass (g); DQI Dickson quality index; T1 = 100% peat; T2 = 80% peat and 20% CRH; T3 = 60% peat and 40% CRH and T4 = 40% peat and 60% CRH. *Means followed by the same letter, in the column, do not differ from each other, according to Tukey's test at 5% probability.

RESULTS AND DISCUSSION

Seedling production (Experiment 1)

The use of different proportions of commercial substrate and carbonized rice husk influenced *L. divaricata* seedling growth during the nursery stage (202 DAS) for all variables analyzed (Table 3). For the height variable, the best results were found in T1 (100% peat) and T2 (80% peat and 20% CRH), which did not differ statistically, while T4 (40% peat and 60% CRH) presented the lowest value for this variable as well as for stem diameter. Saidelles et al. (2009) found similar results, in which the highest proportions of carbonized rice husk also provided a less significant development of *Apuleia leiocarpa* seedlings. This was possibly due to the high proportion of carbonized rice husk, which results in increased macro porosity (Silva et al., 2012), as noted in T3 and T4, which presented airing space (AS) above 35% and easily available water (EAW) below 15%. Treatments T1 and T2 on the other hand presented approximately 28 and 32% of AS, and 21 and 19% of EAW, respectively (Table 1).

The aerial dry mass (ADS) and total dry mass (TDM) presented the highest means when produced with up to 20% CRH, while root development was expressive with up to 40% CRH, which is due to the need for aeration of the root system (Delarmelina et al., 2014). For Trigueiro and Guerrini (2014), substrates with 40 and 60% CRH in mixtures with sewage sludge are best suited for the production of *S. terebenthifolius* seedlings.

However, considering that TDM is a result of net

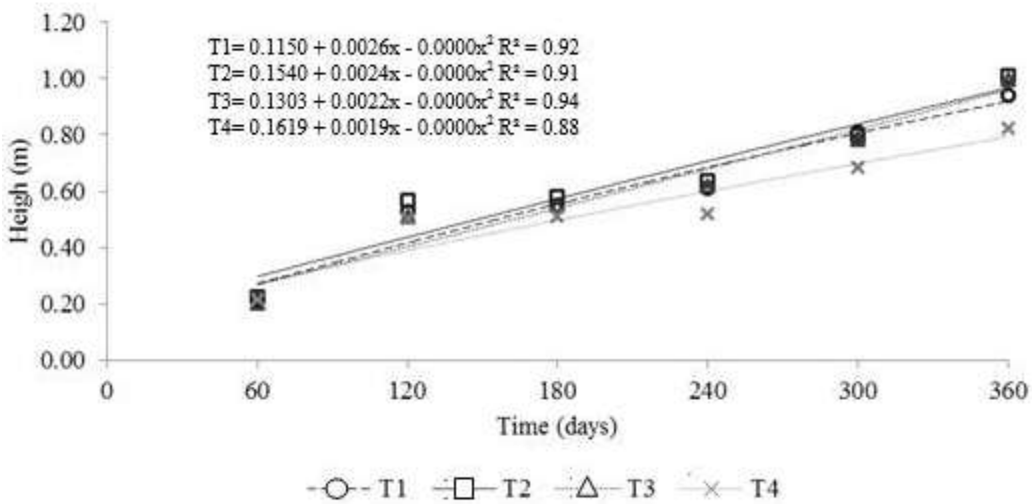

Figure 1. Growth in height (m) of *L. divaricata* seedlings, at 60, 120, 180, 240, 300 and 360 days after sowing in the field as a function of different types of substrate for seedling production. Where: T1 = 100% peat, T2 = 80% peat and 20% HRC, T3 = 60% peat and 40% HRC and T4 = 40% peat and 60% HRC.

photosynthesis, the proportion of 40% CRH can be considered a proper mixture, thus confirming *L. divaricata* that substrates composed of 20 to 40% of porous materials provide better growth conditions for plants produced from seeds, as proposed by Wendling et al. (2002).

The Dickson quality index (DQI) confirmed the results obtained for most of the variables evaluated, thus indicating that the DQI reduces with the increase in the percentage of CRH in the substrate composition. Similar behavior was observed by Oliveira et al. (2014) when testing different substrates for seedling production of *Eucalyptus* spp. and *Corymbia citriodora*, with the substrate composed of 75% CRH, which presented the least significant results for this variable in comparison with 25 and 50% mixture of CRH.

Planting in the field (Experiment 2)

At 30 and 60 days after planting in the field, a higher seedling survival rate was observed with values of 99.5 and 97% of survival, respectively. These percentages were similar in all treatments and are within the limits described by Carvalho (2003), who mentioned survival in experimental plantations ranging from 72 to 100%. The high survival rate may be related to the ruggedness and adaptability of the species, which even in acidic soils and with considerable nutritional deficiency (Table 1), obtained elevated values.

For the height variable (Figure 1), it was observed that at 60, 120 and 180 days after sowing, there was no difference between the substrates, although the highest values observed in all measurements were for seedlings produced in 80% peat and 20% CRH (T2) and 60% peat and 40% CRH (T3).

At 240, 300 and 360 days after sowing, treatments T1, T2 and T3 showed very similar values, differing only in T4, which presented the lowest mean growth (height). These results partially confirm the values found in the experiment held in the nursery (Experiment 1), where T1 and T2 exhibited the greatest growth in height, while T4 the lowest growth for this variable.

Regarding height growth at the time (Figure 1), a significant increase was perceived between the first and second measurements in all types of substrates, contrary to what was observed regarding the two subsequent measurements. This was likely due to the unfavorable weather conditions of the following season, characterized by low temperatures and shorter photoperiod (April to August) in the study region. Growth becomes expressive once again in the fourth measurement, with the end of winter and early spring for all types of substrates, and which remained elevated until the final measurement (September to November). These results corroborate with Neves et al. (2006), who stated that several species have their growth interrupted in the colder seasons, restarting growth in the spring, with the increase in temperature and day length.

For the stem diameter (Figure 2), the seedlings showed

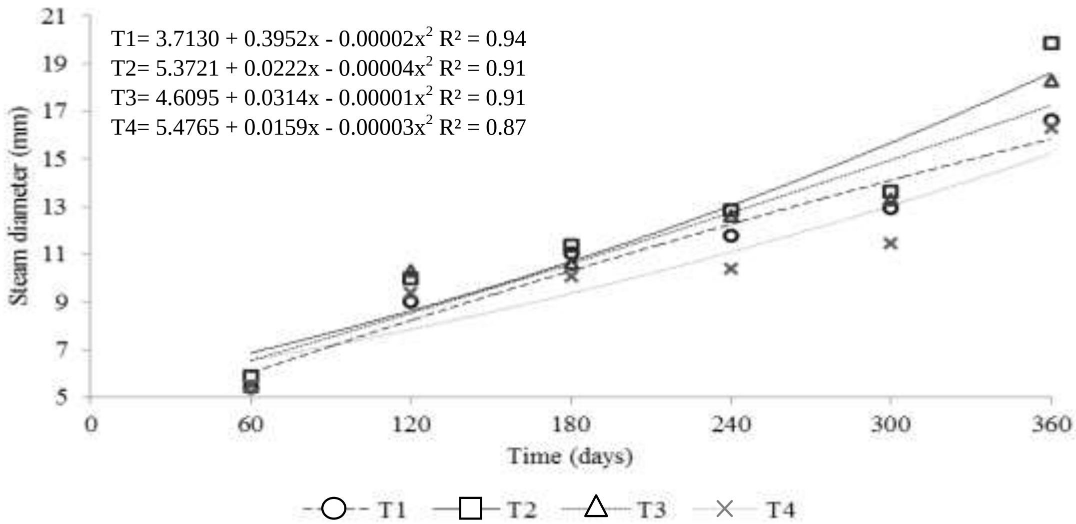

Figure 2. Growth in stem diameter (mm) of *L. divaricata* seedlings, at 60, 120, 180, 240, 300 and 360 days after sowing the field according to the type of substrate for seedling production. Where: T1 = 100% peat, T2 = 80% peat and 20% HRC, T3 = 60% peat and 40% HRC and T4 = 40% peat and 60% HRC.

no difference in the first three evaluations (60, 120, 180 days) for all substrates. At 240 and 300 days after sowing, T2 and T3 showed the highest average SD, while T4 presented the lowest average in the same evaluation period. In the last measurement, this growth behavior was maintained, with the highest mean in T2, thus standing out among the other treatments and the lowest mean verified in T4.

According to Gonçalves et al. (2000), a mixture with 70 to 80% of an organic component and 20 to 30% of a compound that increases macroporosity provides appropriate substrates for seedling production. In *L. divaricata*, high percentages of CRH in the composition of the substrate must be avoided, as evidenced in T4, which presents 60% CRH in its composition, providing the lowest values for both variables evaluated. Stem diameter growth (Figure 2) behaved similarly to height growth (Figure 1), which showed increased development in hotter periods (September to March) and decreased development in the colder seasons (April to August), although maintaining the same response in height in relation to the substrate. Another factor that may have influenced the results is the ruggedness of the species studied, which can adapt to different environments, whether the environment is dry or wet, shallow or rocky (Carvalho, 2003).

Treatments T2 and T3 exhibited similar growth for the variables analyzed in the field, despite T3 presenting lower values for most of the observed variables in the nursery. This tendency was confirmed by Gasparin et al. (2014), who reported that although a substrate composed of 60% peat and 40% CRH did not provide the best result in the nursery, it did not differ from other substrates, when the *Cabralea canjerana* seedlings were transferred to the field. Such responses indicate the importance of the confirmation of the nursery results after immediate planting, especially in the first year, a period during which the seedlings need to overcome weed competition.

In this sense, the use of substrates consisting of 20% to 40% CRH is recommended as a way of reducing production costs, since this is a residue of rice production that causes no harm in the initial development of the species in field planting.

Conclusion

L. divaricata seedlings produced with up to 40% of carbonized rice husk and mixed with commercial peat-based substrate presented adequate initial growth in the field, although the best performance of the seedlings in the nursery occurred with up to 20% of carbonized rice husk. Growth responses of *L. divariacata* seedlings in the nursery were more efficient when associated with the performance of seedlings in the field.

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