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Full Length Research Paper

Effects of reduced spacing on maize productivity, CO_2 assimilation and gas exchange

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The objective of this study is to evaluate the interference of reduced spacing in the physiological and characteristics production components of maize hybrids (*Zea mays* L.). Four line spacings (95, 80, 60 and 40 cm) were tested using three commercial hybrids (H1, H2 and H3) in Senador Guiomard, Acre, Brazil. The experimental design of randomized complete blocks was used in subdivided plots. The experiment lasted four months, where the parameters measured were CO_2 assimilation and gas exchange, water use and carboxylation efficiencies and productivity. Reduction in spacing did not influence the photosynthesis, with slightly differences at stomatal conductance and transpiration. However, it was observed that the H3 presented higher efficiency of water use and carboxylation at the larger spacings. Moreover, there was an increase in the number of ears and grain yield per hectare in reduced spacing, with H3 plants presenting a superior mass of 100 grains among the cultivars. It is concluded that H3 (P4285YHR) presents essential physiological characteristics favouring yields at reduced spacings compared to crops requiring larger spacing. In addition, reduced spacing lines for the maize crop do not reduce atmospheric CO_2 assimilation, resulting in larger productivity per cultivated area among the three tested hybrids.

Key words: Production, photosynthesis, *Zea mays.*

INTRODUCTION

Maize is widely cultivated around the world, in many different soils and climate, mainly because of its large domestication. Nevertheless, its origin is from America (Werle et al., 2011). At the level of world production, Brazil takes the third place, standing behind United States and China (ABIMILHO, 2017).

Brazilian states with the largest production of maize grains in 2015/16 were Mato Grosso do Sul (9000 kg ha^{-1}), followed by Paraná (7953 kg ha^{-1}) and Goiás (7800 kg ha^{-1}). At the North region, Acre state is in an intermediary position, which had a productivity of 2350 kg ha^{-1}, in the same period (CONAB, 2017). The low productivity of Acre can be attributed to use of low-yield cultivars by the producers in addition to inadequate use of plant spacing among lines, reaching one meter (Queiroz et al., 2015).

If it is possible to increase the plant density using reductions in the plant spacing with the objective to improve grain production; thus, the whole system can be more efficient and competitive with the same planted area (Testa et al., 2016). However, high plant density of maize might increase the negative effects of drought conditions (Ferreira et al., 2014), in addition to more intraspecific competition (Sangoi et al., 2010). This

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rivalry among plants highly affects production amount and quality, and breaks the efficiency of utilization of environmental resources, particularly in the physiological trends associated with photosynthesis (Marenco et al., 2014).

In order to evaluate the influence of plant spacing reduction on the physiology and production of maize hybrids grown in open fields, the objective of this work is to assess physiological and production parameters of maize plants cultivated at different levels of spacing and using three maize hybrids.

MATERIALS AND METHODS

The experiment was carried out at the São Pedro Farm in 2016-17, located at Senador Guiomard, AC, Brazil (9°50,9' S; 67°26,4' W). The soil of the experimental area is classified as dystrophic red argisol, medium texture to clay (Rodrigues et al., 2003). Previous soil analysis performed at the 0-20 cm profile revealed the following parameters: pH = 5.4; P = 10.4 mg dm^{-3}; K = 45.3 mg dm^{-3}; Organic Matter = 20.6 g dm^{-3}; Al = 0.25 $cmol_c$ dm^{-3}; Ca = 6.5 $cmol_c$ dm^{-3} and Mg = 2.5 $cmol_c$ dm^{-3}. Using the Köppen classification, the region is categorized as Am, humid and hot equatorial, with well-defined drought period, accentuated at June, July and August (Costa et al., 2012).

The experimental design was random blocks, with subdivided parcels and four replicates. Treatments were combinations of maize hybrids with different spacings. Maize hybrids were 2B 655 PW (H1); AG 7088 PRO3 (H2) e P4285 YHR (H3) while different spacings were 40, 60, 80 and 95 cm among lines, reaching a final number of 125,000; 83,333; 62,500 and 52,632 plants by hectare, respectively. The selected hybrids were in the test phase to be recommended for open field cultivation in the region. Parcels had 96 m^2 of area, each one was divided in four sub-parcels of 24 m^2. Plants positioned at the parcel limits were discarded from the measurements. One week before sowing, weeds in the area were controlled by using glyphosate (systemic herbicide from glycine-derivate group).

In the minimum cultivation system, seeds were sown manually, using spacing holes as explained above to set the treatments; and the line spacing was 20 cm in all treatments, using one seed per hole. Fertilizing was performed based on soil analysis and recommendations by Coelho (2006). The applications contained 60 kg P ha^{-1}, 80 kg K ha^{-1} and 120 kg N ha^{-1} (20% basis, 35% in V4 state and 35% in V8 state) adjusting the fertilizers distribution among the different spacings. Pest and weed control were performed at December 9th of 2016 and January 21st of 2017 using glyphosate (1920 g ha^{-1} of the active ingredient). In order to control *Deois flavopicta* S., the insecticide Decis was applied, a contact product of the pyrethroid group, using 5 g ha^{-1} of the active ingredient.

The following gas exchange parameters were evaluated: Net photosynthesis (P_N), stomatal conductance (g_S), CO_2 intercellular content (Ci) and leaf transpiration (E). Water use efficiency (WUE) and carboxylation efficiency (CE) were calculated by the relation between the PN and E or Ci, respectively. Gas exchange measurements were performed using an infrared gas analyzer - IRGA, LI-6400XT model (Li-Cor Inc. Lincoln, USA). These evaluations were made at the flowering stage VT, between 10 A.M. and noon, at the flag leaves of each measured plant. During the measurements, photosynthetically active photon flux density (PPFD) was maintained at 1000 µmol m^{-2} s^{-1} and the CO_2 concentration in the gas analyzer chamber was 380 µmol mol^{-1}.

Morphological characterization was performed when the plants were with the male inflorescence completely visible. The following parameters were evaluated: leaf area (cm^2), plant height (m), ear insertion height (m) and stalk diameter (mm). Leaf area was evaluated measuring every photosynthetically active leaf of a plant, considering those with more than 50% of green leaf area (Borrás et al., 2003). Photosynthetically active leaf area (A) was estimated by the Equation 1:

$$A = \Sigma (C * L * 0.75) \quad (1)$$

A – leaf area (cm^2);
C – length from base to the tip of the leaf (cm);
L – larger width of the leaf (cm).

At the same time, the average height of the plants, average height of the ear insertion and stalk diameter were measured. For these measurements, a ruler and pachymeter were utilized. Ten plants within each sub-parcel were evaluated. At the time of harvest (120 days after sowing), the following parameters were evaluated: total ears (ears ha^{-1}), grains per ear (grains ear^{-1}), mass of 100 grains (g) and grain yields (t ha^{-1}). After the ears were harvested, the grains were weighed and water content was determined, making it possible to estimate the grain weight corrected to 13% of humidity. The results were estimated to 100 grains. Grains yield was measured and corrected to the humidity content (Equation 2):

$$P13\% = [Po (100 - U) / 0.87] / 1000 \quad (2)$$

P13% - grains yield (t ha^{-1}) corrected to the 13% humidity;
Po - [stand ha^{-1} x parcel yield (kg) / parcel stand];
U - grain humidity in the harvest (%).

Normality of the data was tested using a Shapiro-Wilk test and analysis of variance; and, if significant, means were compared by a Scott-Knott test ($p \leq 0.05$), using ASSISTAT software (Silva and Azevedo, 2016).

RESULTS AND DISCUSSION

Concerning the CO_2 assimilation and gas exchange measurements, the results were not different with respect to net photosynthesis; but they showed changes for the other evaluated parameters. The different spacing of plants or the kind of hybrids used did not affect net photosynthesis (P_N) in any of the treatments. On the other hand, intercellular concentration of CO_2 (Ci) was altered by hybrids and spacing. At 95 cm of spacing, H3 showed 30% less Ci compared to H1 and H2. However, when results were determined for different spacings, the Ci for H1 and H2 was not affected when the spacing was reduced; but H3 showed a larger Ci value at the 60 cm spacing (Figure 1B).

Stomatal conductance (g_S) was significantly different only at the larger spacing (95 cm), with H3 plants showing lower g_S in this treatment (33%) (Figure 1C). Finally, leaf transpiration (E) showed similar results to g_S, with H3 presenting lower E compared with the other hybrids at 95 cm spacing, but with a slight decrease at the minor spacing as well (Figure 1D). These results were also found by Gomes et al. (2011), who found no variation among photosynthetic values in maize plants grown at 50, 70 and 90 (cm) spacings of lines. In order to maintain the photosynthesis rate when there are reductions in stomatal aperture, it has to be more efficient to absorb CO_2 inside the leaf mesophyll (Lemos et al., 2012). This was observed in the H3 hybrid. Even with higher stomatal conductance and decreased CO_2 concentration, phosphoenolpyruvate

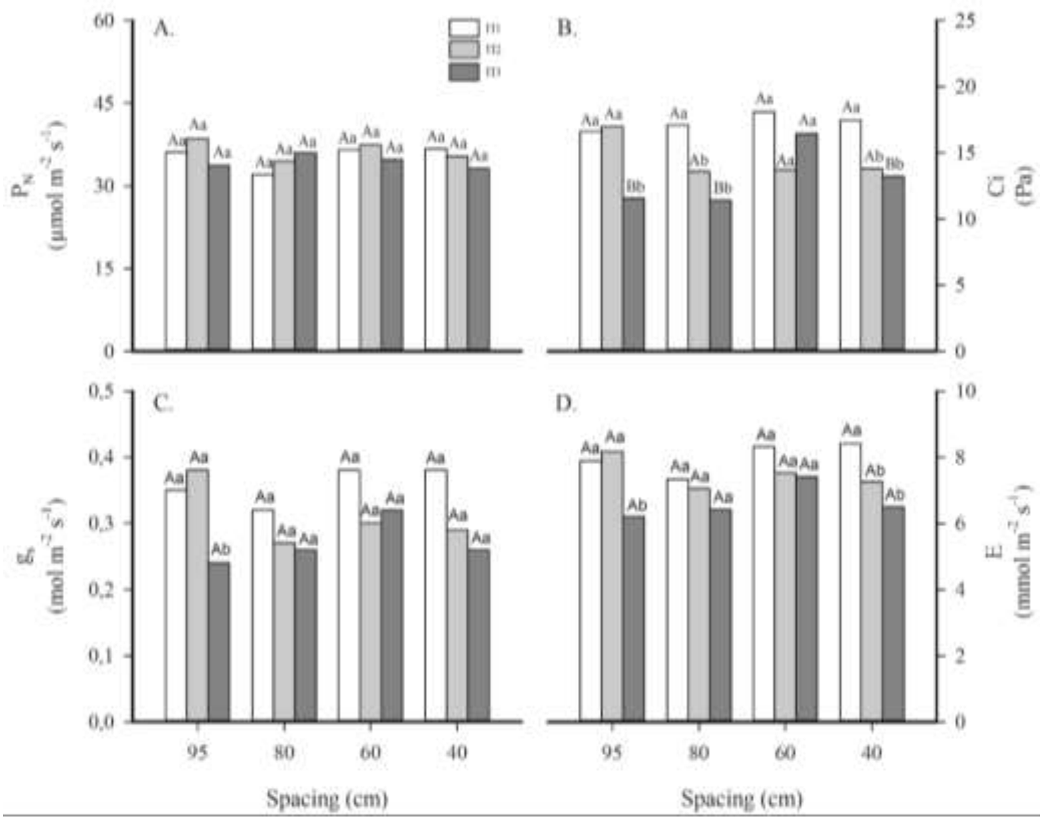

Figure 1. Net photosynthesis (A), intercellular CO2 concentration (B), stomatal conductance (C) and transpiration rate (D) of the hybrids in different spacings. Means followed by the same letter, lowercase between hybrids and upper case for spacing, do not differ statistically (p>0.05) by the Scott-Knott test.

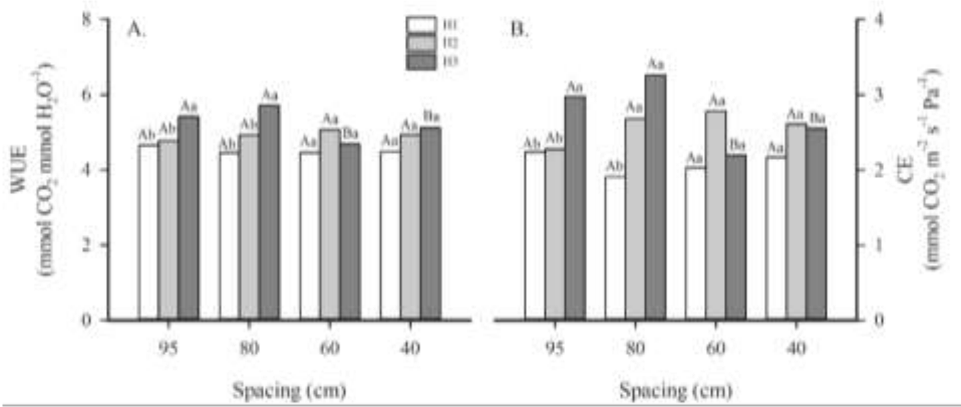

Figure 2. Water use efficiency (A) and carboxylation efficiency (B) of the hybrids in different spacings. Means followed by the same letter, lowercase between hybrids and upper case for spacing, do not differ statistically (p>0.05) by the Scott-Knott test.

carboxylase (PEPC) acts efficiently, favoring maintenance of the photosynthetic potential in C4 plants such as maize (Walter et al., 2015).

Water use and carboxylation efficiencies (WUE and CE, respectively) were calculated using collected data from P_N, E and Ci. WUE was greater for H3 plants grown at the 95 and 80 cm spacings, compared with the other hybrids (Figure 2A). Probably these results are a consequence of the lower transpiration rate in these plants. However, when the spacing was reduced below 80 cm, WUE of the H3 plants was not significantly different from the other hybrids. Similarly, CE was more pronounced for H3 plants in comparison to H1 and H2 plants when grown at the 95 cm spacing, but was significantly different only in relation to H1 plants at 80 cm spacings (Figure 2B).

C4 plants, which contain a highly effective enzyme to assimilate atmospheric CO_2 are consequently very

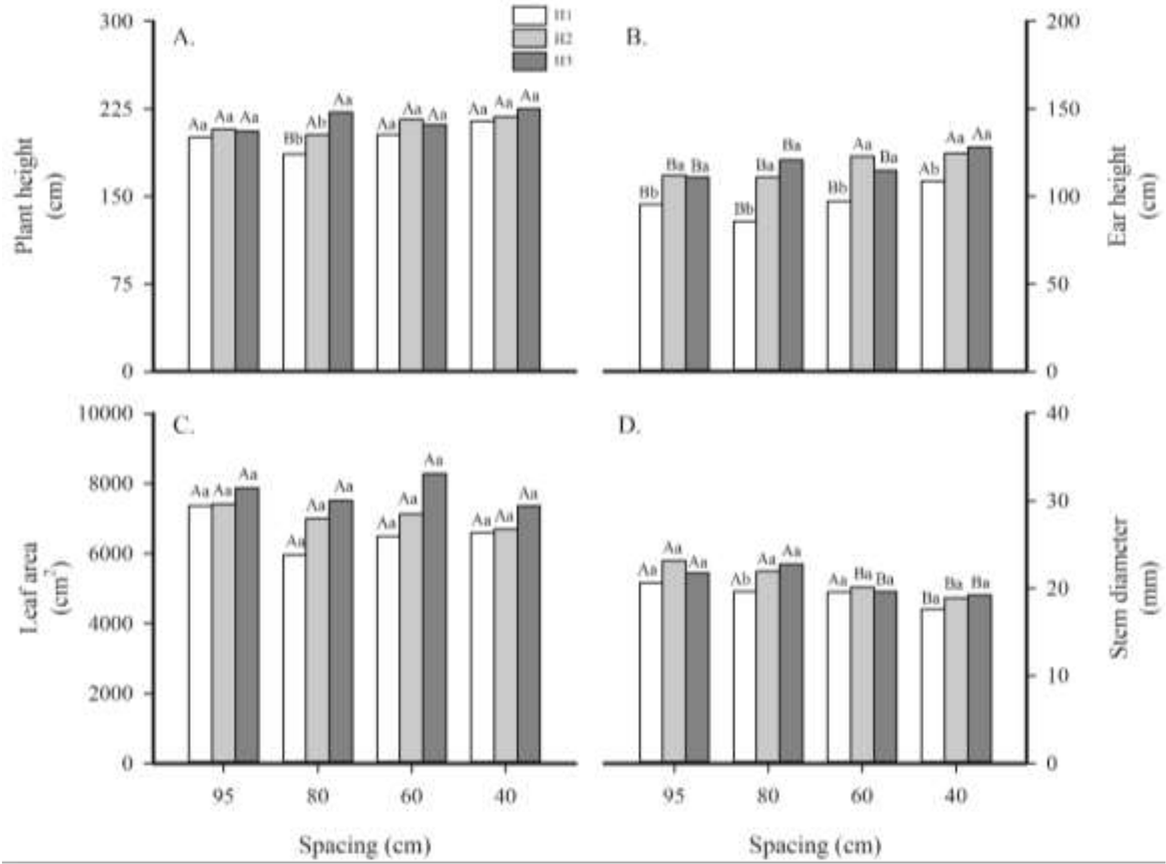

Figure 3. Growth variables of the hybrids in different spacings. Means followed by the same letter, lowercase between hybrids and upper case for spacing, do not differ statistically (p>0.05) by the Scott-Knott test.

efficient photosynthetically. However, when these plants are under stress, they reduce stomatal conductance and leaf transpiration, possibly reducing photosynthesis but increasing photosynthetic and water use efficiencies (Hartzell et al., 2018). Evaluating growth, there are some significant differences ($p<0.05$) among hybrids and spacing for the parameters of plant height, ear height, and stem diameter (Figure 3). However, there were no verified significant variations for leaf area. Plant hybrids achieved more than 200 cm average height. Moreover, there were statistically significant variations among hybrids in the 80 cm line spacing treatment, where H3 plants showed higher height than the other hybrids. Nevertheless, only the H1 plants showed differences in plant height for a spacing at 80 cm; with the 186.2 cm average, being lower than the height values for the other two hybrids. According to Lima et al. (2016), plant height is a characteristic that is conditioned by the plant genotype. This is similar to what we found for H2 and H3 hybrids that responded similarly in height. Calonego et al. (2011) did not find significant differences in plant height as well.

Referring to ear height, there was variation among hybrids (Figure 3B). Across all spacing treatments, H1 plants showed statistically significantly lower mean ear heights than H2 and H3, whereas the latter were similar in mean ear heights. Analysing spacing, H2 plants were the hybrid with the higher mean ear height at 60 cm, presenting 122.7 mean cm for ear height, but at 40 cm, both H2 and H3 are significantly different in mean ear height compared to H1.

According to Sangoi et al. (2010), at places with high density of plants and low line spacing, there is a high intraspecific competition to obtain light, favouring the culm elongation. This can be the reason that in this work, only the mean ear height was affected with less variation of the plant height. With regards to stem diameter, it was observed that at 95 cm spacing, hybrids were similar. But, at the 80 cm spacing, H1 showed lower stem diameter than the other hybrids. At the smaller spacings (60 and 40 cm), there was no statistically significant difference. Evaluating spacing lines, hybrid plants cultivated at the larger spacings (95 and 80 cm) showed larger mean stem diameters than the ones grown at the smaller spacings (60 and 40 cm). According to Strieder et al. (2007), plant density is the main factor that alters the stem diameter, also increasing the number of dominating plants, characterized by low development and lesser stem diameter. This situation can increase the amount of broken and bedding plants, being prejudicial especially during the mechanical harvest, with significant losses of the maize crop (Rezende et al., 2015).

In the productivity components, there were differences ($p<0.05$) only for the productivity and ear by hectare parameters among the different spacings

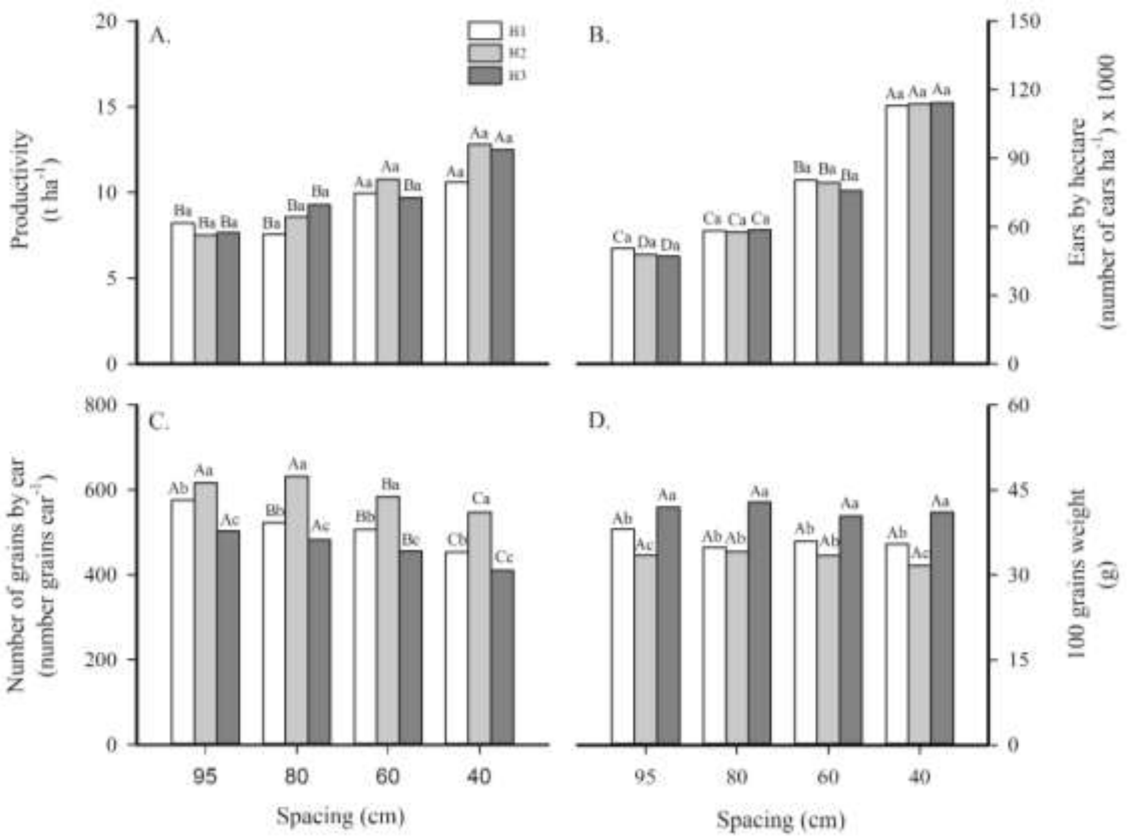

Figure 4. Productivity variables of the hybrids in different spacings. Means followed by the same letter, lowercase between hybrids and upper case for spacing, do not differ statistically (p>0.05) by the Scott-Knott test.

(Figure 4). Nevertheless, the number of kernels by ear was variable among hybrids and spacing while the 100 grains weight was different only among hybrids. Productivity varied from 7.53 to 12.81 t ha^{-1}, increasing while the spacing between lines was reduced. It is important to notice that H2 and H3 hybrid plants were more productive (approximately 80%) at the smaller spacings, compared with the larger spacing lines. Lima et al. (2016) observed that yield increased with the increment of the plants number by area. Similar results were found by Lana et al. (2009) and Modolo et al. (2010), who found more kernel productivity at reduced spacing.

Checking the number of ears per hectare, it can be seen that hybrids did not vary at the same spacing. Nevertheless, examining only the different spacing lines, there was a 2-fold increase in mean ear number per hectare comparing the data for the smaller spacing (40 cm) with the larger one (95 cm). Serpa et al. (2012) verified that the ear number per square meter was linearly influenced by the plant density. Still, they reported that an increase in the plant's density can cause female sterility, directly influencing the number of fertile ears per area.

The number of grains by ear was higher for the H2 hybrid, with a larger average at all spacings. Evaluating the number of grains per ear in relation to the spacing treatments, this parameter was reduced concomitantly with reduced spacing lines, independently of hybrid treatments. According to Testa et al. (2016), at reduced spacing lines and higher plant's density, there is a reduction of the ear size, consequently reducing the grain amounts and weights. However, these same authors report that the key to increased productivity with high density of plants is the higher number of harvested grains per unit of area. The different spacing lines had no significant impact on the 100-grains weight (Figure 4D). Though, it was observed that H3 plants showed a higher average for this parameter at all spacing lines, mainly at the treatments with more density of plants. However, Li et al. (2015) reported different results when planting with higher densities. They found grains with lighter and smaller cores, reducing the plants' productive potential.

Conclusions

(1) The hybrid P4285 YHR (H3) showed higher water use and carboxylation efficiencies at the smaller spacing lines, because they presented lower stomatal conductance, while keeping similar values of photosynthesis compared to the other tested hybrids.
(2) Reduced spacing lines of the maize crop do not reduce atmospheric CO_2 assimilation, resulting in larger productivity per cultivated area among the three tested

hybrids.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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African Journal of Agricultural Research

Full Length Research Paper

Management and organization of shina-hamusit and selamko irrigation schemes to preliminary assessment in South Gondar Zone, Ethiopia

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The utilization of small-scale irrigation schemes plays a significant role in addressing food security problems as a supplementary with rain-fed or irrigation agriculture in the basin and as a whole in the country. The conveyance efficiency values at Shina-Hamusit was 73%, while at Selamko it was 59%. These values showed that the conveyance loss is huge in both irrigation schemes, especially at Selamko that has canals maintenance as the major identified problem, resulting in water logging in the farmlands through seepage. The application efficiency of Shina-Hamusit ranges from 47 to 57%, while it ranges from 53 to 64% for Selamko. This indicates that, application efficiency at field level in Selamko is better than Shina-Hamusit. This may be associated with the farmer's perception, type of crops grown and excess rainfall. Water users are responsible for the overall water management including maintenance of the main diversion in irrigation schemes. In the studied areas at Shina-Hamusit scheme, there is collection of water fee and the Woreda cooperatives promotion desk auditors have not held the documents and audited the accounts while at Selamko there is no water fee now, and no maintenance of canals; the reasons for this may be weak committee and delay of payments by the farmers. The Selamko local irrigation authority maybe suggested as reforming their institutional water management and taking of water fee before irrigation, and to observe the activities of the water use association and assist them in implementing efficient water management and water saving strategies. At Shina-Hamusit scheme, market and road accesses were the major constraints that make the scheme to be inefficient whereas at Selamko major constraints concentrated on upstream and downstream irrigation scheme maintenance, potato disease, water logging, as well as market constraints.

Key words: Conveyance efficiency, application efficiency, major constraints, water distribution and management, water fee.

INTRODUCTION

Water resources are under enormous pressure due to increasing demands for more and better quality water. These demands are in turn conditioned by social, political and environmental factors. The growing difficulties to

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ensure that water demands are met have led to greater competitiveness for scarce water resources among traditional sectors of water users, namely agriculture, industry and urban supply. One of the keys to overcoming these problems lies in the agricultural sector, given that irrigation, particularly in arid and semiarid areas, is the chief consumer of water; accounting for 70% of consumption worldwide. However, water is considered an increasingly scarce and valuable resource requiring rigorous management and extreme care (Moreno-Pérez, 2013).

The research and development community, like the farmers in the world's semi-arid areas, often cites low and/or unreliable rainfall as the most important factor contributing to low productivity and food insecurity. Overcoming water scarcity by irrigation appears self-evident, hence the promotion of irrigation development in the developing world, and specifically in sub-Saharan Africa (Mancosu et al., 2015).

Variables such as operation and maintenance, institutional settings, and land and water resources determine the sustainability of irrigation systems. Improving the performance of irrigation systems requires setting some relevant criteria for performance and identifying indicators that can enhance the performance level. The performance of the irrigation schemes are distinguished as internal process indicators and external (comparative) indicators (Molden et al., 1998). From their perspective, internal indicators are useful to assess performance against system specific operational targets and for comparison of schemes. Determining the volume of water applied by irrigators at the field scale is a prerequisite for achieving sound irrigation management at higher scales (Lorite et al., 2013).

In Ethiopia, irrigation performance assessments are conducted rarely due to lack of field level data. Some attempts have been made to assess the scheme level performance of some irrigation schemes (Awulachew and Ayana, 2011). There is a need to develop aggregate indicators that provide a clue to the performance of irrigation development under limited data availability. Therefore, this paper evaluates the performance of the Shina-Hamusit and Selamko small-scale irrigation schemes in South Gondar zone, Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study carried out at two modern small-scale irrigation schemes at Shina-Hamusit and Selamko micro earthen dams, South Gondar Zone, Amhara Region, Ethiopia, were serving for relatively longer period in the basin (Figure 1). The study schemes were selected based on site accessibility and availability of water in the reservoir.

Shina-Hamusit irrigation scheme: This is situated in Metsele Kebele of Dera *Woreda*, adjacent to Fogera *Woreda* in the south. It can be accessed via the road leading to Gondar, about 35 km away from Bahir Dar. From Hamusit village, the Shina community is located about 9 km away in the northwest direction. It is located at 11.55°N and 37.6°E, with an altitude of 1560 m.a.s.l. The topography is *woinadega* agro-ecological zones. The annual rainfall ranges between 1000 mm and 1500 mm. The rainy season is from March to November. The dominant crops grown in the *Woreda* are *teff*, barely, wheat, finger millet, rice, maize, sorghum, faba bean, pea, lentil, vetch, niger seed, linseed, Ethiopian mustard and sun flower. Root crops such as potato and sweet potato, and vegetables such as shallot and garlic are also produced in the *Woreda* (Dera *Woreda* Planning and Economic Development Case Team, 2011) (Eguavoen et al., 2012).The irrigation system is significant and the command irrigated land is 105 ha.

Selamko irrigation scheme: this is located in Farta *Woreda* of South Gondar Zone. The scheme is located 3 km from Debre Tabor town. The geographical location is 11.53°N and 38.02°E with an elevation of 2519 m.a.s.l. The annual rainfall ranges from 1500-2000 mm. The average annual temperature is 17°C. The major crops grown are potato, wheat, barley, *teff*, millet, faba bean, lentil and chickpea. It is a hundred percent *woyna-dega* agro-ecological zones. The command area is 63 ha (Eguavoen et al., 2012).

DATA COLLECTION

Secondary data

Secondary data were collected from *Woreda's* office, using questionnaire surveys from the water users (10% water users from the total water users). The questionnaires were designed to get the perception of the farmers on the water distribution within the project. Furthermore, a participator approach discussions was held with beneficiary farmers and development agents.

Primary data

Canal water flow, water management practices, bulk density, soil moisture and soil texture were measured from respective sites, which is described below in details.

Soil sampling and analysis

Approximately 200 g of soil sample taken from the 2 irrigation schemes at an interval of 0-10 cm, 10-30 cm, and 30-60 cm for bulk density (BD); and 0-60 cm depth for determination of soil physical properties like soil texture, field capacity (FC) and permanent wilting point (PWP). Particle size distribution was determined using the Bouyoucos hydrometer method. Bulk density was determined by taking undisturbed soil sample from the site using core sampler method. FC and PWP water content were determined by pressure membrane plate apparatus, whereas total available water (TAW) was obtained by subtracting PWP from FC (Estefan et al., 2013).

$$\text{TAW} = \left(\frac{\text{FC} - \text{PWP}}{100}\right) \text{x BD x d} \tag{1}$$

Where TAW = Total available water (cm), FC = Field capacity (percentage), PWP = Permanent wilting point (percentage), BD = Bulk density (g cm^{-3}) and d = Depth of root zone (cm).

The physical properties of the studied scheme soil (texture, bulk density, field capacity, permanent wilting point and total available water) are given in Table 1. The texture of the soil ranges from silty clay loam to clay for Shina-Hamusit while for Selamko ranges from silt to clay. The average values of FC (weight basis), PWP (weight basis) and BD (g/cm^3) for Shina-Hamusit was 0.43, 0.26 and 1.2

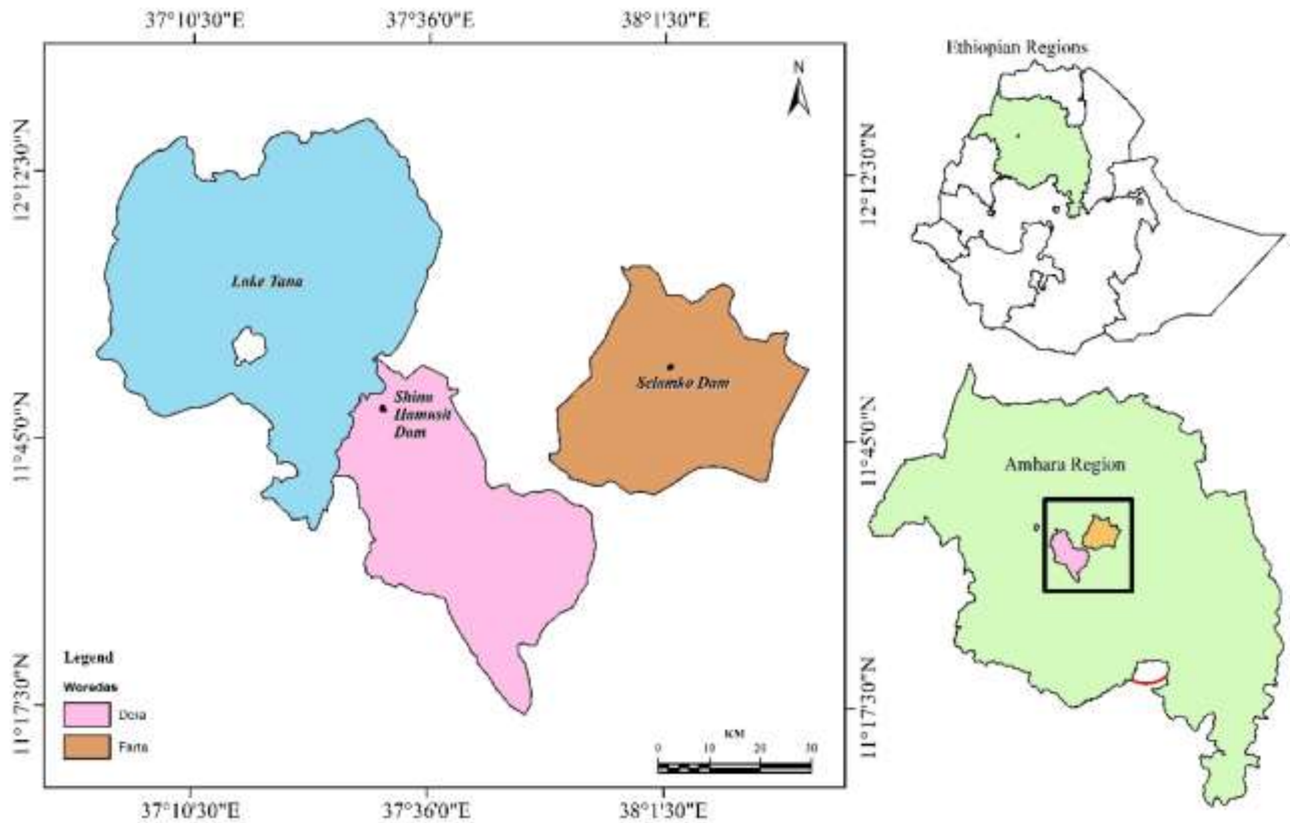

Figure 1. Map of study sites.

Table 1. Physical soil properties at Shina-Hamusit and Selamko irrigation schemes.

Schemes	Farmer's Field	Soil depth, cm	Bulk Density, gm/cm^3	FC (%), gravimetric	PWP (%), gravimetric	Soil texture class
		0-10	1.2			
	Head	10-30	1.2	43	25	Silty clay loam
		30-60	1.3			
		0-10	1.2			
Shina-Hamusit	Middle	10-30	1.3	47	29	Clay loam
		30-60	1.3			
		0-10	1.1			
	Tail	10-30	1.3	40	24	Clay
		30-60	1.2			
		0-10	1.2			
	Head	10-30	1.3	38	22	Clay loam
		30-60	1.3			
		0-10	1.2			
Selamko	Middle	10-30	1.4	38	23	Clay
		30-60	1.4			
		0-10	1.2			
	Tail	10-30	1.3	38	23	Silt
		30-60	1.3			

FC=field capacity, PWP=permanent wilting point, %=percent, gm/cm3=gram per centimeter cube, cm= centimeter.

while for Selamko was 0.38, 0.23 and 1.3, respectively.

Description of the experimental setup

The water application efficiency were measured at the initial and mid-season stage of the crop growing season; the conveyance efficiency were measured twice in the main irrigation time during February-April and March-May at Shina-Hamusit and Selamko irrigation schemes, respectively. Three sample research plots that belong to different farmers chosen purposely from the head, middle and tail ends of the schemes, and all the necessary measurement and data collection conducted at the two schemes. At Shina-Hamusit, the size of each plot was 451, 242 and 335 m^2. All the chosen plots planted with maize and *teff*. On the other hand, at Selamko, the plot area was 172, 377 and 845 m^2. Potato was planted on all the chosen plots.

Conveyance efficiency

The conveyance efficiency measured twice on the main canal by measuring discharge at two different points. The discharge calculated by the floating method in which the velocity of the water flowing in the main canal was estimated by timing the passage over a predetermined distance of the canal of some material floating on the water surface. The estimated velocity was then multiplied by the cross sectional area of the particular section of the canal to obtain the discharge. The first measurement of discharge conducted in the upper position of the main canal. Dried wooden floating material was placed on the upper end of this canal section and the time it takes to reach the length of the canal section was recorded. This test replicated three times and the average time used. To obtain a per meter velocity, the total length of the section was divided by the average time obtained.

The partitioned cross sectional area of the canal was also estimated by measuring the average depth and width of this same canal section. At that point, an average discharge was calculated by multiplying the partitioned cross sectional area (A) with the average flow velocity (V). The second measurement was taken starting from the distance of the canal mark downstream from the first test site. The comparison of discharge from the first and second site provided an estimate of the conveyance loss, or the decrease in discharge from the first to second measurement, and average conveyance efficiency was calculated as (FAO, 1989):

$$E_c = \frac{V_d}{V_c} \times 100 \tag{2}$$

where, E_c is the conveyance efficiency (percentage), V_c is water flowing (m^3/sec) into the canal section and, V_d is water flowing (m^3/sec) out of the section.

Application efficiency

The application efficiency was calculated from the fields of farmers that was growing crops at each irrigation schemes, and situated in the head, middle and tail end of the water users. For moisture content determination, 144 soil samples were taken to the laboratory. For every three plot, soil samples were taken before and after 24 h irrigation from 0-10, 10-30 cm and 30-60 cm depths per test pit at initial and mid-season stages of the crop with replication for each. Samples were initially weighed with a sensitive balance immediately after sample collection on the field. The water content was measured gravimetrically by weighing the sample after oven drying at 105°C for 24 h. The dry weight fraction of each sample was calculated using the equation (FAO, 1989; Estefan et al., 2013).

$$\theta_w = \frac{W_w - W_d}{W_d} \times 100 \tag{3}$$

Where, θ_w is soil water content on a dry weight basis (percentage), W_w is wet weight of the soil (g) and W_d is dry weight of the soil (g).

The moisture contents of the soils collected from the selected fields at different depths was determined and the amount of water retained in the soil profile within the specific root zone before and after irrigation measured. The water content on a volume basis was estimated as the product of gravimetric water content and bulk density.

To determine the amount of water applied by the irrigators to the field, cutthroat flumes were installed at the entrance of test plot. Frequent readings were taken while the farmers irrigated the test plots. Irrigation continued until the farmers suggested that enough water has been applied to the field. The average depth of irrigation water passing through the flume and the respective time were recorded for each test plot irrigated. The discharge was calculated using the following equation (FAO, 1989):

$$Q_f = C_f * W * (h_u)^{nf} \tag{4}$$

where, Q_f is discharge flow, W is throat width of the cutthroat flume, h_u is depth of water flow in the flume, C_f and nf flow coefficients

Then, the application efficiency (E_a) in the selected fields calculated using the equation below (FAO, 1989):

$$E_a = \frac{D_r}{D_f} \tag{5}$$

where, D_r is depth of water in the root zone (mm) and D_f is depth of water applied to the field (mm).

The depth (D_f) of water applied to the field was estimated by dividing the average total amount of water applied to the field by the area irrigated.

Method of data analysis

The internal process indicates that the efficiency of the schemes, particularly the conveyance and application efficiency of the scheme are analyzed descriptively but separately for both schemes. The data collected through questionnaires are analyzed descriptively using Statistical Package for Social Science (SPSS).

RESULTS

Soil physical properties

Organization of the schemes

Shina-Hamusit irrigation scheme: Originally, the project was designed and constructed by the Government of Ethiopia and FINIDA in 2000 E. C. and the structures, even if poorly maintained, still exist. The

Dam comprise one main canal, 15 tertiary canals, 10 catch drains and 11 field drains. The main canal is 2,911m long and is not fully lined but is lined partially. The secondary canals are unlined earthen canals. A number of division boxes along the primary canals are used to divert the water into the secondary canals.

The scheme is gravity pump. The pumps work for ten hours per day, but do not work for 5 holidays (Sunday, Saturday, Saint Mary, Miracle Michael, and God day) every month. Almost all farmers used furrows. The spade equipment was used to open and close furrows while irrigating their crops. The main crops grown in the irrigation project area were maize, potato, sweet potato, onion, oat, *teff*, pepper, tomato, barely, vetch, garlic and cabbage. Rice was the dominant irrigated crop.

The farmers themselves, including their family, do all the farming practices. However, during peak times like harvesting, some farmers are forced to hire additional labor on daily wage basis. In the irrigation project, there was no rule or restriction on the farmers regarding what type of crop to produce. The farmers have the right to choose what type of crop to plant as far as the crop is profitable and the water allocation is adequate to produce the selected crop. The development agent (DA) guides the farmers when they plant and what type of crops to plant. The types of crops grown are selected based on the market condition, crop resistance to disease, water availability and ease of management.

Farmers sell their products by themselves based on the market price. Individual farmer covers the production costs like fertilizer, chemicals and labor, without the involvement of the association. The Water Use Association (WUA) is relatively well organized than Selamko. It has more than 160 beneficiaries, out of which 120 are members while the remaining 60 and other poor farmers are not members owing to lack of awareness about the association and its functions, and lower level of livelihood.

The board of directors of the association has seven members and three controlling committee with ten members. There were two temporary employees hired to attend to the structures in the scheme and one storekeeper. Women involvement in management and decision-making are relatively considered, and one of the controlling committee was a female. The association uses basic financial documents. The *Woreda* co-operatives promotion desk auditors or government responsible offices do not hold the documents and audit the accounts. The organization meets twice per month; one meeting held by all members of the association to raise issues for discussion and decide on time, while the second meeting held for board of directors to discuss some issues. Payment of annual water fee from all water users is the main source of income for the association. Each beneficiary is expected to pay an annual water use fee. Currently, there are 20 members in the low category, 57 members for medium and 43 members for high-level and water users pay 15, 20 and 25 Ethiopian birr, respectively based on livelihood level and their irrigated area per year. In addition to this membership fee, registration fee, and water fee from potential beneficiaries, penalties paid are also additional sources of income for the association.

Division leaders are responsible for distribution of irrigation water to their respective team leaders according to the schedule. Team leaders are mandated to ensure fair water distribution among the beneficiaries. An internal regulatory system is used by the association to ensure fair water distribution and to manage conflicts among beneficiaries. All beneficiaries must obey the internal regulation whether they are members of the association or not. According to the response of development agent, the main production constraints experienced are seepage, siltation, problem creator farmers, marketing coordination, road, and unbalanced price.

Selamko irrigation scheme: Originally, the project was designed and constructed by the Government of Ethiopia in 2001 E.C., and the structures maintained. The dam had one main canal and five secondary canals. The main canal was not fully lined. The secondary canals were unlined earthen canals except one. Five division boxes along the primary canals are used to divert the water into the secondary canals.

The irrigation project had a gravity pump. A representative farmer assigned by the association throughout the year manipulates the gate at diversion weir. The discharge of the main canal varies from time to time, while considering the head, middle and tail sites. The discharge in the canal is controlled by metal operated gate. The pumps works every day for twelve hours. All farmers use border irrigation. Spade equipment is used to open and close borders while they irrigate their crops as flood irrigation. The main crops grown in the irrigation project area are potato, maize, garlic, barley, carrot, bean, shallot, onion, pepper, lentil and cabbage. Among the mentioned crops, potato is the dominant irrigated crop produced, covering about 57% of the irrigable land during the study. These crops are grown both during rainy and dry seasons. During the rainy season, even if the rain was sufficient for the crop, irrigation water supplemented when vegetable crops are transplanted.

The farmers themselves, including their family, do all the farming practices. In the irrigation project, there was no any rule or restriction on the farmers regarding what type of crop to produce. The farmers have the right to choose what type of crop to plant and the profit, as well as the amount of water allocated to irrigate the selected crop. In addition, the DA guides the farmers' on the type of crops produce and when they should be planted. The types of crops to be grown are selected based on the compatibility of the crops to the soil and climate, market condition, crop resistance to disease and ease of

Figure 2. Overfilling of unlined canals and livestock interference at Selamko (left 3) and lined and unlined main canals at Shina-Hamusit (right 2) irrigation schemes.

management. The individual farmer covered their cost of inputs like fertilizer, herbicides, seed and labor by themselves.

Selamko irrigation scheme had relatively poor organized WUA than Shina-Hamusit. It had 161 beneficiaries out of which 114 were members, while the remaining 47 were not members because of a lack of awareness about the association and its functions. Out of the command area, there were more than 40 potential beneficiary members in the scheme. The association has seven directors of board and three controlling committees with ten members. There were two temporary employees hired to attend to the structures in the scheme. The salary of the operator and two temporary employees were forage from the dam of upper stream grassland; and the main canals cleared by the members themselves once a year. Women involvement in management and decision-making are considered, and one of the controlling committee is a female. The organization meets monthly where all members have a chance to raise issues for discussion and decision on time.

The committee of the association had the right to collect money from the members, but they were weak to collect. Payment of annual water fee from all water users was the main source of income for the association, but not at the present. Membership fee, registration fee, water fee from potential beneficiaries and penalties paid were additional sources of income. For year 2009 and 2010, water users paid 2.5, 5-10 and 16-24 Ethiopian birr/ha for low, medium and higher-level livelihood for water use, respectively. The association documented this collected water fee. The *Woreda* cooperatives promotion desk auditors have not audited the accounts. Currently, starting from 2011, there is no water fee due to weak associations and absence of government enforcement for water fee.

Division leaders are responsible for distribution of irrigation water to their respective team leaders according to the schedule. Team leaders are also mandated to ensure fair water distribution among the beneficiaries. An internal regulation system is used by the association to ensure fair water distribution and to manage conflicts among beneficiaries. All beneficiaries must obey for this regulation whether they are members of the association or not. Nevertheless, the committees were too weak to execute the regulation. According to the response of development agent, the main production constraints experienced include entrance of polluted water by Gris, soap and car wash from the city, siltation, marketing coordination, road, and unbalanced price.

Conveyance efficiency

The computed conveyance efficiency values at Shina-Hamusit and Selamko irrigation schemes are 73 and 59%, respectively (Table 2). The conveyance efficiency of Shina-Hamusit was better than Selamko. This is probably associated with the frequent cleaning of the canals in Shina-Hamusit scheme. The fact also reveals that the canal in Selamko was ponding substantial water due to infrequent cleaning of canals, unlined canal, and theft of pipe gates lock (close button) from the lined canals to withdraw water illegally (Figure 2). This may be the most probable reason for this big water loss. In brief, there were conveyance losses in both schemes.

Application efficiency

The application efficiency values at Shina-Hamusit scheme were 57, 56 and 47%; and at Selamko were 64, 53 and 56% at the head, middle and tail site of the fields, respectively as presented in Table 3. Looking into depths of water applied at Shina-Hamusit, more water was applied at tail site than head site; while regarding application of efficiencies, head site was most efficient. On the other hand, over application at Selamko scheme as compared to within the field sites observed at middle site. The lower application efficiency in Shina-Hamusit at tail site was due to the perception of the farmers that application of more water means more production and applying more water offsite contributes to longer irrigation frequency (scheduling). On the other hand, the lower application efficiency at Selamko was due to farmer’s perception that application of excess water could damage

Table 2. Computed conveyance efficiency of Shina-Hamusit and Selamko irrigation schemes.

Schemes	Canal section	Average depth = h (cm)	Average Width $=b_1$ (cm)	Average Width $=b_2$ (cm)	Area (cm^2)	Length (cm)	Elapsed time (sec)	Velocity (cm/sec)	Discharge (cm^3/sec)	Conveyance Efficiency (%)
Shina-Hamusit	UMC	75	60	-	4488	1300	17	61	275045	73
	LMC	52	93	-	4764	1250	24	42	200843	
Selamko	UMC	20	60	2	619	1000	16	49	30380	59
	LMC	14	43	2	314	1000	14	57	17422	

NB= mean velocity = 0.8*(length/time), the coefficient used for float methods measurement is 0.8. At Shina-Hamusit scheme, the canal has rectangle shape while at Selamko scheme and the canal is trapezoidal shape, and $a=1/2(b_1+b_2)*h$, where, a=area, b_1=base one or bottom water width, b_2=base 2 or top water width, h = height which is the depth of the water in the canal. UMC=upper main canal, LMC=lower main canal, cm=centimeter, cm^2 =centimeter square, cm/sec=millimeter per second, cm^3/sec=centimeter cube per second, %=percent.

Table 3. Computed application efficiency of Shina-Hamusit and Selamko irrigation schemes.

Schemes	Farmer's site	Area (m^2)	Total volume (m^3)	Applied depth (mm)	Depth stored (mm)	Application efficiency (%)
Shina-Hamusit	Head	451	91	203	115	57
	Middle	242	45	184	104	56
	Tail	335	90	267	125	47
Selamko	Head	172	30	177	113	64
	Middle	377	90	238	127	53
	Tail	845	161	190	107	56

m^2 =meter square, m^3 =meter cube, mm=millimeter, % = percent.

Table 4. Major constraints identified at Shina-Hamusit and Selamko irrigation schemes.

Major problems identified	Shina-Hamusit (n=12)		Selamko (n=12)	
	Frequency	Percentage of respondents	Frequency	Percentage of respondents
Labor shortage	3	25	3	25
DA support problem	0	0	4	33
Input shortage	1	8	6	50
Maintenance problem	1	8	12	100
Market problem	12	100	9	75
Road access problem	12	100	4	33
Water shortage	2	17	0	0
Water utilization conflict	2	17	6	50
Disease problem	5	42	11	92
Water logging problem	-	-	10	83
Thief	-	-	4	33

n= number of respondents.

the planted potato crops at middle site due to seepage.

Major constraints decreasing the efficiency of the schemes

The major constraints identified at Shina-Hamusit irrigation scheme presented in Table 4. According to the respondents revealed that market and road access constraints were the major constraints that made the scheme inefficient; while disease, labor and water shortages, water utilization conflict, input shortage and maintenance were minor constraints.

At Selamko irrigation scheme, the respondents revealed that the major constraints concentrated on upstream and downstream irrigation scheme maintenance, disease, water logging, market, input shortage, and water utilization conflict; while theft, road access and DA support, and labor shortage were minor constraints (Table 4).

RESULTS AND DISCUSSION

The comparison of the performance of irrigation systems will help the present status of these systems. Therefore, to improve the irrigation system management and the irrigation practices, frequent performance evaluation is imperative. The results of the study are discussed below. As shown in Table 2, the conveyance efficiency values at Shina-Hamusit and Selamko irrigation schemes were 73 and 59%, respectively. Different scholar found different values of conveyance efficiency in different continents. For instance, Gomo et al. (2014) found conveyance efficiency values with the range of 40-86.4%. The conveyance efficiency values found in this study were comparable to results mentioned above. Nevertheless in both schemes, the value of conveyance efficiency is far below the recommended value for concrete-lined canals of 85%. This pronounced leaks due to reduced canal capacity due to growing of weeds and silt deposition causing water to overflow canal banks, seepage and theft of pipe gates lock at Selamko; while at Shina-Hamusit, it is due to evaporation and canal seepage.

As shown in Table 3, the application efficiency values at Shina-Hamusit irrigation scheme ranges from 47 to 57% while at Selamko, it ranges from 53- 64%. Similarly, the water application efficiency in various irrigation systems in Turkey is 31 to 83% at plain, unlevelled and levelled land (Oylukan 1970) as cited by Korkmaz et al. (2009). Dissimilarly, the values range from 64.7-85.4% on site measured at different irrigation schemes in Tigray, Ethiopia (Behailu et al., 2005), and Korkmaz et al. (2009) found to be 65.6, 69, and 72.6% at head, middle and tail on site-measured values in Tukey, respectively. The application efficiency values in the study sites were within the acceptable limit except the head site at Selamko, and lower than or within the above studies. The reason for poor water application efficiency may be because small scale irrigations is associated to absence of the required trainings by farmers, the type of irrigation system employed which is predominantly border and furrow irrigation, the slopes of irrigable fields, absence of knowledge of irrigation time and scheduling by farmers. However, farmer's water management at field level in Selamko is better than Shina-Hamusit except at the middle site. This may be associated with the farmer's perception, type of crops grown and excess rainfall. Farmer's perception at Selamko scheme is that application of excess water can damage the planted potato crops; while at Shina-Hamusit farmers' perception is that application of more water means more production.

At Shina-Hamusit, scheme road access and market were the major constraints that make the scheme inefficient. Hamusit town was the only main market center, which is 9 km far from the farm of the community without infrastructure. Most of the time, farmers sold their outputs to private traders at site. The irrigation cooperative was limited due to its financial and business capacity to assemble and market farmers' produces. The perishability and bulkiness nature of the farm products forced farmers to sell their produce with the price determined by the buyer. Farmers had no chance to arrange the price. Accordingly, the net return they got income from reduces and discourages farmers; they consequently cut down their contribution and effort to make the scheme more efficient.

Whereas at Selamko, irrigation scheme, upstream and downstream irrigation scheme maintenance, disease, water logging, and market were the major constraints. The main household crop production objective was to produce enough food that covers the annual household consumption. Even though potato and barley crops produced more, it is used for home consumption and the surplus crops from consumption accommodated by the local market. Canal maintenance was another constraint that results from water logging constraint at the farmlands due to unlined canals and absence of canal cleaning and failure to pay water fee to improve operation and maintenance of canals.

Conclusions

The comparison of irrigation schemes indicates the weaknesses and strengths, which were helpful for managerial and technical practices. Water users at Selamko were responsible for the overall water management including maintenance of the main diversion but have not paid irrigation water fee since 2011. The farmers suggest this is due to weak committee and delay of payments. Contrary to this, the collection of water fee will help the operation and maintenance and other managerial activities of the irrigation systems. Therefore, in order to ensure successful collection of fee, it is suggested that institutional reforms and taking of fee should be done before irrigation, for water management. In addition, the local irrigation authority recommended the observation of the water use association activities and assistance should be given to them to implement efficient water management and water saving strategies.

Conveyance efficiency was good at Shina-Hamusit than Selamko due to frequent cleaning of canals, therefore water users at Selamko should clean the canals like that of Shina-Hamusit users for better performance. The application efficiency of Shina-Hamusit irrigation scheme was poorer than Selamko scheme, but both schemes have low efficiency. Therefore, subsequent training should be given to farmers. At Shina-Hamusit, scheme road access and market were the major constraints that made the scheme e inefficient. The concerned body should facilitate organization setting in their *Woreda's* for producers to have a fair price on commodities, and should give emphasis on the construction of road to enhance the schemes productivity. Whereas at Selamko irrigation scheme, upstream and downstream irrigation scheme maintenance, disease, water logging, and market were the major constraints. The institutional reform and committee's mobility may resolve the maintenance and water management of the scheme, while for the disease constraints further detail research study will be needed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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ABBREVIATIONS

BD, Bulk density; **E_a**, application efficiency; **cm,** Centimeter; **E_c,** conveyance efficiency; **A,** cross sectional area; **^{0},** Degree; **°C,** degree centigrade; **d,** depth of root zone; **DA,** development agent; **Q,** discharge; **E,** east; **FINIDA,** Finnish International Development Assistance; **V,** flow velocity; **FAO,** food and agricultural organization; **FC,** field capacity; **g/cm^3,** gram per centimeter cube; **ha,** hectare; **IWMI,** International Water Management Institute; **Km,** Kilo Meter; **m.a.s.l.,** meter above sea level; **m^3,** meter cubic; **m^2,** meter square; **mm,** millimeter; **N,** north; **No,** number; **%,** percent; **Sec,** second; **ULL,** upper main canal; **LMC,** lower main canal; **PWP,** permanent wilting point; **TAW,** total available water; **WUA,** water use association.

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Nutrient cycling in multifunctional agroecosystems with the use of plant cocktail as cover crop and green manure in the semi-arid

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Plant cocktails used as cover crop present a significant multifunctional resource compared to monoculture, which may increase functional diversity within crop rotation and is particularly effective for designing mixtures with characteristics that increase the multifunctionality and sustainability of the agroecosystem. The objective was to evaluate sustainable agroecosystems models that improve the efficiency of nutrient cycling for crops. The treatments were arranged in four blocks in a split-plot design with two soil management (tillage and no-till) systems and three cropping systems (2 plant cocktails [PCs] and 1 natural vegetation [NV]). C/N ratio, lignin content, dry biomass (DB) production and decomposition, nutrients accumulation and mineralization by PCs and NV were evaluated. Decomposition and release of nutrients were monitored by the litterbag-method. PCs had a DB production twice higher than NV, essential for the adoption of no-tillage systems. The order of nutrient release was K> N> Ca> P> Mg. PCs as cover crops and green manure, with or without predominance of legumes and use of a no-tillage system, could be a technological strategy in agroecosystems for nutrients cycling in semi-arid regions.

Keywords: plant mixture, soil management, mineralization rate, macronutrient, sustainable agriculture.

INTRODUCTION

Nowadays, land use systems that are mostly based along the lines of sustainable development has been soughted, such as adoption of no-tillage system. By means of a global meta-analysis, Pittelkow et al. (2015) observed that the use of a no-till system, with use of cover crop, promotes increased agricultural production compared to conventional systems in arid regions, particularly where water is limiting for crops growth. However, management

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recommendation for the use of cover crops in semi-arid region is currently limited by the lack of information (Liebig et al., 2015).

The direct influence on improving soil conditions by cover crops is the reduction of nutrient losses by leaching and erosion, maintaining of soil moisture, increasing of soil water infiltration, control of natural vegetation, supply of available nutrients and increasing biological diversity, especially when using leguminous species and improving soil structure when using grasses (Almeida et al., 2016).

Many studies have shown the benefits of the single cultivation of cover crops, but the value of varied cover crop plant cocktails (PC) has received less attention (Finney and Kaye, 2017). Recent recommendations support the use of PC instead of a single species in semi-arid environments, such as the use of leguminous and non-leguminous species, like grasses and oilseeds, to promote mulch stability in no-tillage system, but it still requires more detailed scientific studies (Wutke et al., 2014). The simultaneous cultivation of leguminous and non-leguminous species in the same area can be an effective tool to merge the advantages of individual species (Liu et al., 2017).

However, understanding the residue decomposition dynamic and nutrients immobilization/mineralization in the soil is necessary to identify the most adapted species combination (Xavier et al., 2017). Those species must have characteristics related to climate adaptation and tolerance to drought, biomass production and soil cover efficiency, biological fixation of nitrogen (BFN), decomposition rate and cycling and accumulation of nutrients (Roberts and Mattoo, 2018).

The knowledge of DB production and dynamic of nutrients release from cover crops residues is essential to promote their maximum persistence on the soil surface, which contributes to the maintenance of moisture, soil protection and the success of sustainable production system in a semiarid environment (Giongo et al., 2011). Cover crops with high biomass production and nutrient recycling are essential to maximize the productivity of successional crops in a no-till system (Neto et al., 2011). In this context, Alvarenga et al. (2001) recommended 6.0 Mg ha^{-1} of dry biomass for obtaining a good soil cover in no-till system in Cerrado (Brazilian Savanna), but the amount of dry biomass can vary according to the type of plant and the edaphoclimatic conditions of the region, which affect the biomass production and the decomposition process.

The evaluation of plant residues decomposition added to the soil by cover crops provides a better understanding of nutrient supply for important commercial crops (Xavier et al., 2017). Typically, species are grouped into two decomposition classes using C/N rate value to separate them in those with rapid decomposition and with slow decomposition rate, which is accepted a C/N value close to 25 as references to separate these groups (Wider and Lang, 1982). Leguminous species, mainly due to its high N content and nutrient cycling, presents rapid decomposition and release of nutrients (Talgre et al., 2017). However, besides C/N values, other factors have an influence on decomposition process, which are lignin and polyphenols contents and their relationships associated with weather, the microorganisms action and soil conditions (Carvalho et al., 2015).

In semi-arid regions, where high temperatures and scarcity of water in drought periods prevail, is acceptable that plant residues decomposition is very low. However, research carried out by litterbag-method in a semi-arid of Enthiopia showed a high plant residue decomposition even when litterbags were placed on the soil surface (Abera et al., 2014).

Several species of cover crops plants can be used to improve the cycling of nutrients in the soil (Isbell et al., 2017). The mix of species, with the use of legumes and non-legumes, should take a biomass production with intermediate C/N, providing soil cover for more time and a better synchronization between nutrients released by cover crops residues and nutritional demand of the commercial crop in succession (de Sá Pereira et al., 2017). The favorable effects of cover crops on soil properties and crop yields are recognized, due to biomass production, nutrient cycling capacity, especially from deeper layers, and subsequent nutrients release by plant residues decomposition (Mendonça et al., 2015).

Multifunctional agriculture is attracting more and more attention among scientists and is considered as a way to obtain sustainability, since it focuses on the complex correlation and interactions between the agroecosystem, natural environment and socioeconomic development (Zhen et al., 2017). Plant cocktails used as cover crop presents a significant multifunctional resource compared to monoculture, which may increase functional diversity within crop rotation, and is particularly effective for designing mixtures with characteristics that increase the multifunctionality and sustainability of the agroecosystem (Blesh, 2017). The design of polycultures that maximize functional diversity may lead to agroecosystems with greater multifunctionality (Finney and Kaye, 2017).

A practical method was assessed with the use of mixed cropping as cover crops and green manure as a technological strategy for nutrients cycling in irrigated systems in semiarid regions. However, few are the studies about the dynamics of nutrients and information on the effect of mixed cropped as green manures on the nutrient cycling (Tarui et al., 2013). This study presents the nutrient cycling potential of multifunctional Agroecosystems when plant mixtures are cultivated before melon crop produced in irrigated areas from semiarid. It provides an approach to identify the critical processes and opportunities for improvements in the conventional crop system that may support producers in the task to improve soil quality and reduce cost with fertilizers.

The objective was to evaluate sustainable agroecosystems models that improve the efficiency of nutrient cycling for crops.

MATERIALS AND METHODS

Area descriptions

The study was conducted in an experimental field located at geographical coordinates 9°08'S, 40°18'W, 365.5 m a.s.l from June 2014 to June 2015 in the initial phase of a long-term experiment. The soil is classified as ultisol eutrophic red-yellow plinthic (EMBRAPA, 2018), with the following physical and chemical characteristics at the depth of 0 to 0.20 m: 83.1% of sand; 11.9% of silt; 4.9% of clay; pH (H_2O) 6.6; organic matter 5.82 g dm^{-3} (wet oxidation-diffusion); P 47.34 mg dm^{-3} (Mehlich-1); H+Al 1.21 mmol dm^{-3} (KCl-extraction); K (Mehlich-1); Ca (KCl-extraction); Mg (KCl-extraction); and Na (Mehlich-1) exchangeable, 11.0, 18.5, 7.8, and 0.7 mmol dm^{-3}, respectively, the sum of bases (S) 31.8 mmol dm^{-3}; capacity cation exchange (CEC) 43.4 mmol dm^{-3} and base saturation (V) 71.6% (EMBRAPA, 2011). The climate is classified as BSwh' according to the Köppen classification system, with an average annual temperature of 26.8°C, the average annual rainfall of 360 mm, and the climax vegetation called Caatinga (xeric shrubland and thorn forest). Data of mean temperature and precipitation were measured at the agrometeorological weather station located at experimental farm (Figure 1).

Experimental design and plant

The PCs cultivation preceded a yellow melon crop (*Cucumis melo* L.). The successor culture planted on the PCs and NV residues. The treatments were arranged in four blocks in a split-plot design. Two tillage treatments as main plots had dimensions of 30 × 10 m. Conventional tillage (T) comprised plowing and disking compared to no soil disturbance in NT plots. Sub-plots treatments, 10 × 10 m, comprised three cropping systems, two different compositions of plant cocktail and one natural vegetation cover.

Mixes of plants used as cover crops present greater multifunctionality than monocultures. The greater the diversity of cover crops, the greater the services from agroecosystems, mainly due to the specific ecological characteristics inherent to each species used (Blesh, 2017). Different from other studies, which use few species as cover crops, this work contemplated a larger number of plants to compose the plant cocktail, with potential already known in semiarid region. The PCs composition used with conventional tillage and no-till treatments are: PC1 - 75% legumes + 25% non-legumes; PC2 - 25% of legumes + 75% non-legumes; and NV - natural vegetation. Fourteen species included in the composition of PCs, comprised legumes, oilseeds and grasses, including the following species: (A) Legumes - calopo (*Calopogonium mucunoide*), velvet bean (*Stizolobium aterrimum* L.), grey-seeded mucuna (*Stizolobium cinereum* Piper and Tracy), Crotalaria (*Crotalaria juncea*), rattlebox (*Crotalaria spectabilis*), jack beans (*Canavalia ensiformes*), pigeon pea (*Cajanus cajan* L.), lab-lab bean (*Dolichos lablab* L.); (B) no legumes: sesame (*Sesamum indicum* L.), corn (*Zea mays*), pearl millet (*Pennisetum americanum* L.), milo (*Sorghum vulgare* Pers.), sunflower (*Helianthus annuus*), andcastor oil plant (*Ricinus communis* L). The natural vegetation composed of the predominant species: benghal dayflower (*Commelina benghalensis* L.), purple bush-bean (*Macroptilium atropurpureum*), florida beggarweed (*Desmodium tortuosum*) and goat's head (*Acanthorpermun hispidum* DC).

Data collection

Plant cocktails were cultivated in the second half of June (Figure 1). The seeds were sown in furrows at a spacing of 0.50 m. The irrigation system used was plastic pipes distributed between the rows with drip emitters spaced at 0.5 m and a flow rate of 4.0 L h^{-1}. In order to ensure the seed germination, initially the smaller seeds were distributed, followed by the intermediate size and then the larger, avoiding the segregation effect. Seventy days after sowing, end of September, when most species were in the flowering stage, the PCs species were cut in the spacing of 1 m², with three replicates for each treatment, to evaluate the total aerial biomass production. PC effective as a cover crop was maintained and the other parts were incorporated by a disc harrow to 0.4 m depth. Subsamples of plant cocktails from each treatment were weighted and sent to the Laboratory of Soil (Embrapa - semiarid), stored in a greenhouse at 65 to 70°C for 72 h, and weight again (g kg^{-1}) to estimate the dry matter yield (t ha^{-1}), lignin content (g kg^{-1}) and C/N ratio. Natural vegetation, which grows spontaneously in the area, had a similar procedure for evaluation.

For analysis of residues decomposition and nutrient release by PCs and NV were used for only three experimental blocks. Samples of the aerial biomass of plants cocktails and natural vegetation were used for the confection of litterbags (size 0.3 × 0.3 m, mesh 0.5 mm) with 250 g of wet biomass. There is a clear difference in decomposition rates between shoots and roots, which may also be explained by the differences in the chemical composition of the residue (Talgre et al., 2017). Thus, shoots and roots from the different plants were cut and mixed. According to the treatments design, the litterbags were buried in 0.2 m soil depth or deposited on the soil surface. Only one block was used for litterbags deposition, which was arranged in rows (between the melon crop lines) and identified by stakes with nameplates. After plant residues deposition and during the first 3 months (melon culture lifespan), drip irrigation system was used with drip emitters distributed on the rows with 2.0 m width. For each treatment type, 30 litterbags were used. Sampling was carried out at 0, 14, 21, 50, 78, 105, 141, 172, 208, 236, and 258 days after deposition (DAD) (Figure 1), which 3 litterbags from each treatment were removed from the field. The biomass of the litterbags was cleaned manually, by removing the plant roots which have grown into the inside of the bags, dried at 65°C in a forced air oven until a constant weight and weighed. To eliminate soil contamination, the technique of determining the ash residues suggested by Potthoff and Loftfield (1998) was used. Samples of dried biomass were ground in a stainless steel mill type "Wiley" with 1.0 mm mesh sieve for analysis of nitrogen (N), phosphorus (P), potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg) and total carbon.

For analysis of total C and N was used for the Elemental Analyzer Truspec (LECO USA). P and K were determined by nitric/perchloric acid digestion (Bataglia et al., 1983). The P determination was done colorimetrically by forming the blue-colored complex from molybdate in the presence of ascorbic acid and K, by flame photometry (EMBRAPA, 2011). Ca and Mg were analyzed by atomic absorption spectrophotometry (Bataglia et al., 1983). The lignin content was determined by the acid detergent fiber method (Van Soest and Wine, 1968).

The obtained values were converted into percentage concerning the mass and nutrient content of the beginning of decomposition (To). With those data, the biomass decomposition rate and nutrients release for each treatment were determined. The residue decomposition and nutrient release follow the simple exponential model used by Olson (1963):

$$Mt = Mi\, e^{-kT} \quad (1)$$

where Mt are the remaining percentages of DB and macronutrients after T days and $Mi = 100\%$ when T is equal to zero, that is, the deposition day of the residues on the soil. With decomposition, constant k was calculated with the time required to release 50% (t_{50}) and 95% (t_{95}) of the nutrients, $t_{50} = \frac{ln2}{k}$ and

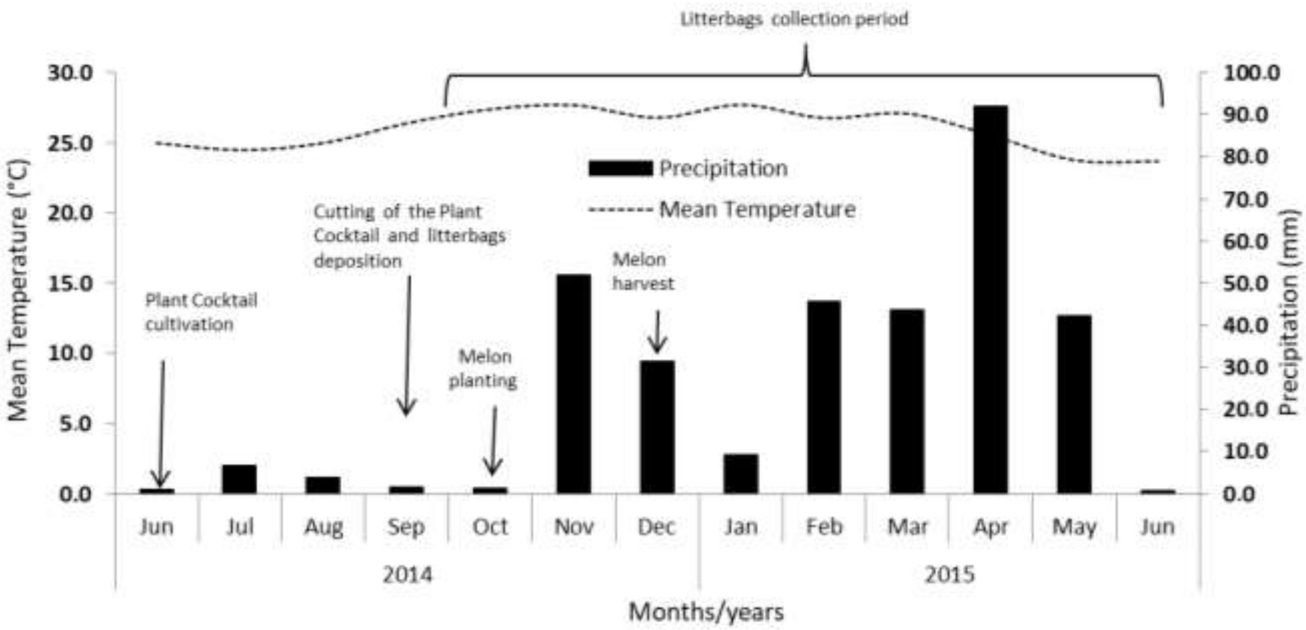

Figure 1. Monthly mean temperature and precipitation, dates of planting, cultural practices, and sampling during the research period in the experimental area.

$t_{95} = \frac{3}{k}$ (Shanks and Olson, 1961). Reorganizing the equation, it was possible to calculate the decomposition constant, or k-value:

$$k = \frac{\ln \frac{Mt}{Mi}}{t} \quad (2)$$

Statistical analysis

The results were statistically analyzed for variance (ANOVA), using the SISVAR® Statistical Software (Ferreira, 2011). The difference between treatment means was assessed by the Tukey test, at 5% probability.

RESULTS AND DISCUSSION

Residues production, content, and accumulation of macronutrients

In a previous work carried out in the same area showed that PCs do not significantly differ among themselves, with mean value of 8.3 t ha^{-1} for PC1 and 9.20 t ha^{-1} for PC2 composition, and NV with a DB representing about 50% of the PCs with 4.50 t ha^{-1} (Giongo et al., 2016).

The biomass production and nutrients accumulation in 2014 by PC1, PC2, and NV are shown in Table 1. Despite not significant, the PC1, with the highest percentage of legumes, showed the highest biomass production (8.86 t ha^{-1}). The NV presented almost 50% less DB production (4.35 t ha^{-1}) than PC1 and PC2. However, the PC2 DB (7.55 t ha^{-1}) was not significantly different from PC1 DB, may be related to the high photosynthetic capacity and carbon-richness biomass of the grasses and the nutrient cycling efficiency of the oilseed plants as well (Giacomini et al., 2003).

In relation to the quantity of residues required to maintain soil protection, the DB production by CPs was higher than the values suggested by Alvarenga et al. (2001), that is, 6.0 t ha^{-1}. In semiarid multifunctional agroecosystems to increase the half-life, to promote the gradual release of the nutrients and the time of cover of the soil it is fundamental that the biomass is not incorporated (Blanco-Canqui et al., 2015).

The DB production can vary significantly with rainfall index, temperature, location and soil fertility (Torres and Pereira, 2014). In relation to NV, must be considered that it holds a varied seed bank, and diverges with soil management, availability of rainfall and photoperiod that could reflect directly on the annual DB production (Borgy et al., 2015).

The plant residues contents of N, P, Ca, and Mg did not differ significantly among the different cover crops tested. Although the content of K was higher in NV, the amount of this nutrient was lower due to the low DB production in comparison to the PCs (Table 1).

With regard to accumulation of nutrients, with exception of K, PC1 and PC2 differ significantly (P <0.05) from NV on the amount of these elements added to the soil. Although it was not statistically significant, the PC1, with a higher proportion of legumes, presented an accumulation slightly larger for all elements. Thus, for PC1 the values of N, P, K, Ca, and Mg reached 284.21, 41.11, 216.95, 240.7, and 62.9 kg ha^{-1}, respectively.

Table 1. Dry biomass production, content, and accumulation of nutrients, lignin and C/N ratio of crop residues.

Treatment	DB	N	P	K	Ca	Mg	Lignin	C/N
		Content						
Composition	**t ha^{-1}**	**g kg^{-1}**						**-**
PC1	8.86^{a}	32.05^{a}	4.63^{a}	24.46^{b}	27.15^{a}	7.09^{a}	103.40^{b}	15.57^{a}
PC2	7.55^{a}	33.75^{a}	5.22^{a}	26.39^{ab}	31.75^{a}	8.36^{a}	107.79^{b}	14.60^{a}
NV	4.35^{b}	27.79^{a}	5.34^{a}	34.99^{a}	32.97^{a}	8.44^{a}	132.06^{a}	16.57^{a}
CV%	21.39	16.16	12.99	21.88	21.58	14.97	18.30	13.83
LSD	1.87	7.55	0.99	9.38	9.9	1.78	17.93	3.28
				Accumulation				
				kg ha^{-1}			**g kg^{-1}**	**-**
PC1	8.86^{a}	284.21^{a}	41.11^{a}	216.95^{a}	240.7^{a}	62.9^{a}	103.40^{b}	15.57^{a}
PC2	7.55^{a}	253.55^{a}	39.60^{a}	202.25^{a}	236.2^{a}	61.2^{a}	107.79^{b}	14.60^{a}
NV	4.35^{b}	120.93^{b}	23.18^{b}	152.26^{a}	143.6^{b}	36.7^{b}	132.06^{a}	16.57^{a}
CV%	21.39	21.15	19.77	30.49	24.34	30.4^{9}	18.30	13.83
LSD	1.87	69.59	10.25	87.00	75.4	7.5	17.93	3.28

Means followed by the same letter are not significantly different by Tukey test at $P < 0.05$. DB: Dry biomass, PC1: plant cocktail 1, PC2: plant cocktail 2, NV: natural vegetation.

Therefore, the N was the nutrient with the highest accumulation followed by K, different from NV that accumulated more K than N. Hence, the plant mixture cultivated PC1 and PC2 reached the follow accumulation order N > Ca > K > Mg > P while NV got the follow order K > Ca > N > Mg > P (Table 1). The presence of oilseeds could have contributed to N accumulation from PC2 which is not different significantly from PC1 (Liu et al., 2018). Both plant mixtures (PC1 and PC2) and spontaneous vegetation (NV) were efficient in K uptake and cycling, indicating that cover crop cultivation is an important strategy to mitigate losses of K by leaching and erosion. It is possible to observe that the performance of NV in nutrient uptake in relation to plant mixtures (PC1 and PC2), without considering phytomass production, was very efficient in nutrient cycling, since there were no significant differences between them.

The amount of nutrient uptake depends on the species, soil fertility, phenological stage in dehydrating the C/N ratio, the planting season, besides the climatic conditions of each study (Fontana et al., 2018).

Decomposition rate of plant residues

The study of plant residues decomposition rate allows checking when and how much of each nutrient is released in the soil, consequently to promote the adjustment of fertilization. Table 2 shows the decomposition constant k, the 50 and 95% decomposition of plant residues. The soil management system changed the decomposition rate of PC and NV. In no-till treatments, the absence of plowing promoted a decrease of the plant residue decomposition kinetics and the maintenance of soil cover for more time. The decomposition of 50% of PCs DB takes approximately 115 days when is not incorporated (NT) in the soil, and around 98 days when is incorporated (T), showing a small difference between the types of soil management. To decompose 95% of the PCs and NV, DB takes around 497 and 424 days, respectively, in NT, and 400 and 500 days, respectively, in T. Although not high, there was a difference in residues decomposition from the surface deposited litterbags than those that were buried. In tropical soils, the higher amplitude of diurnal temperature variation results in higher decomposition than under constant soil temperature condition (Séna Koglo et al., 2017). Unfortunately, we did not record the soil temperature, but high mean air temperature was registered (>25°C) in most months of this experiment (Figure 1). However, differences in soil moisture content probably may also be favoring the decomposition process. Previous studies in the same area showed that soil moisture content in 0.2 m depth was higher in all treatments with PCs under NT than T (Pereira Filho et al., 2016).

C/N values showed no significant differences in all treatments. In addition, those values presented below of the threshold that separate the faster and slower decomposition group (C/N = 25), certainly related to the promotion of intermediate values by PCs. Combined with C/N values, highlight the lignin contents that were significantly higher in NV ($p > 0.01$) than PCs. Lignin inhibits the decomposition of plant residues, accentuating the maintenance of soil cover (Xia et al., 2017). NV had a lower decomposition rate with the half-life of 154 days when not incorporated and 114 days when incorporated in the soil. This can be explained by the fact that NV has

Table 2. Constant of decomposition (k) half-life (t_{50}) and 95% decomposition (t_{95}), of Plant cocktails and natural vegetation with different management.

Plant composition	Soil management	Variables of decomposition equation			
		K (dias^{-1})	t_{50} (dias^{-1})	T_{95} (dias^{-1})	r^2
PC1	NT	0.0060	116	500	0.98
	T	0.0080	98	423	0.82
PC2	NT	0.0060	114	492	0.92
	T	0.0080	102	441	0.86
NV	NT	0.0050	154	667	0.93
	T	0.0070	114	492	0.80

PC1-plant cocktail 1; PC2 - plant cocktail 2; NV - Natural vegetation; NT – No-till, T – Conventional tillage.

higher values of both C/N ratio (16.57) and lignin content (132.06 g kg^{-1}) becoming more resistant to decomposition. In addition, the smaller the N value and the higher the lignin value, the lower is the decomposition rate (Xia et al., 2017). Consequently, C/N and lignin values corroborated with t50 and t95 values found.

The dynamics and decreasing loss of relative dry biomass by PCs and NV are as shown in Figure 2. Based on the exponential model equation, the plant residues presented the relative loss of dry matter in the end evaluated period: PC1, PC2, and NV decomposed 78.73, 79.23 and 68.57%, respectively, when not incorporated and 83.91, 82.71 and 79.25%, respectively, when incorporated in the soil. The kinetics of the decomposition process showed a similar pattern in all treatments, with a fast initial phase followed by a slower one. The initial and rapid phase is related to leaves and other materials less lignified, and the next and slower phase is related to the decomposing of more resistant compounds (Xavier et al., 2017). In addition, the use of drip irrigation during the successor crop life cycle may promote an increase in the decomposition process. This result was also observed by Giongo et al. (2011) in previous studies in the same area.

It was observed that the quantity of biomass produced by PCs did not decompose completely during the study period, essentially for not incorporated treatments, with higher DB quantity compared with values recommended by Alvarenga et al. (2001) for Cerrado regions (Brazilian Savanna) where the rainfall indices are higher than semi-arid regions. It is important that PCs produce a satisfactory amount of mulch for adoption, maintenance or continuation of similar production systems in the region. In semi-arid multifunctional agroecosystems, it is fundamental that the biomass is not incorporated into the soil in order that it increases its half-life, promote the gradual nutrients release and increase the time of soil cover. In addition, the PCs have been demonstrated to be alternatives to supply part of the successional crop nutritional demand, hence contributing to the reduction of production cost by reducing the quantity of fertilizers.

Nutrients released from plant residues

The intensity and duration of rainfall are factors that influence the biomass decomposition and nutrient release (Mendonça et al., 2015). During the study period, with low monthly rainfall averages, typical of the study area, were less than 50 mm, except for April 2015 with 90 mm (Figure 1). The low rainfall observed may not have influenced the nutrients release from residues, considering the presence of water in the soil, due to irrigation during the experiment, and also the overlapped wet bulbs observed.

Table 3 shows the analysis of variance among the types of plant cocktails and types of soil management with regard to decomposition constant k and the release time of 50 and 95% of nutrients by plant residues. It was observed that the treatments with soil tillage there was a higher rate of decomposition, consequently leading to less time of nutrients release. In treatments with soil tilling no significant difference occurred between the soil cover types for k and time of nutrient release.

The results of analysis of variance showed significant results ($p>0.01$) for the variables time, cover crop type and the interaction of time/cover crop type. The kinetics of nutrients mineralization process in all treatments showed a similar pattern, with an initial rapid phase during the first months, when it was released great part of nutrients mainly by incorporated treatments, and followed by a slower release phase.

N is one of the most affected nutrient by no-till system, since the maintenance of residues on the soil surface modifies the processes of immobilization, mineralization, and leaching (Zhang et al., 2016), promoting the reduction of residues decomposition process and causing changes in the availability and loss of N (Frasier et al., 2017). The N mineralization occurred differently between

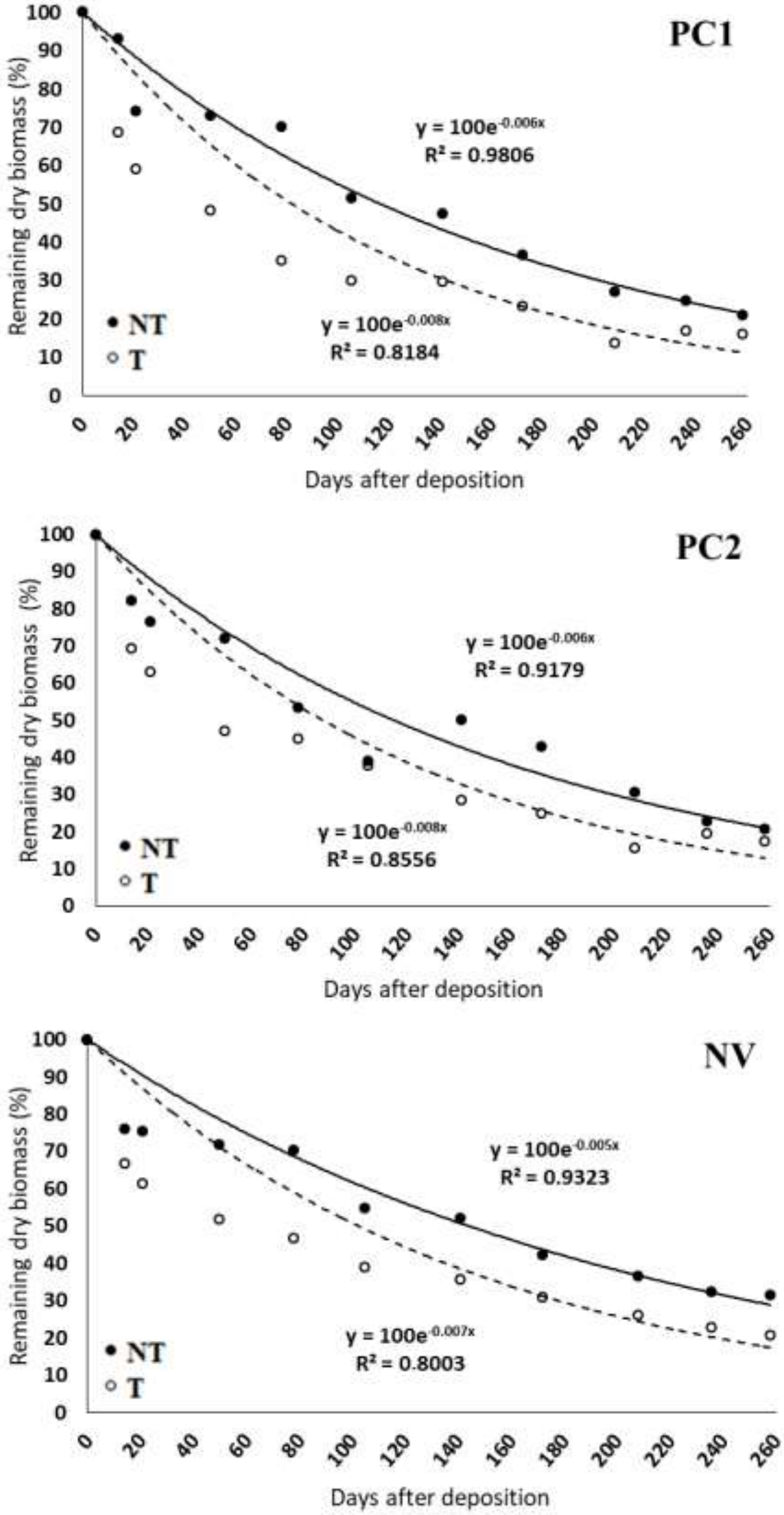

Figure 2. Decomposition of plant cocktail 1 (PC1), plant cocktail 2(PC2) and natural vegetation (NV) with and without incorporation showing two moments of the decomposition process. NT: No-till, T; conventional tillage, DB: dry biomass.

Table 3. Estimated Values of nutrients decomposition constant (k) by exponential model $Mt = Mi\, e^{-kT}$ and nutrients release time of 50% and 95%.

Parameter		k (days^{-1})			t50			t95		
		PC1	PC2	NV	PC1	PC2	NV	PC1	PC2	NV
P	NT	0.0051^{Bb}	0.0063^{Aa}	0.0041^{Cb}	135B^{a}	109^{Ca}	167^{Aa}	585^{Ba}	471^{Ca}	725^{Aa}
	T	0.0062^{Aa}	0.0066^{Aa}	0.0062^{Aa}	110A^{b}	105^{Aa}	111^{Ab}	479^{Ab}	454^{Aa}	480^{Ab}
K	NT	0.0093^{Bb}	0.012^{Ab}	0.0094^{Bb}	75A^{a}	60^{Ba}	74^{Aa}	324^{Aa}	260^{Ba}	319^{Aa}
	T	0.017^{Aa}	0.017^{Aa}	0.016^{Aa}	41^{Ab}	42^{Ab}	42^{Ab}	179^{Ab}	180^{Ab}	181^{Ab}
Mg	NT	0.0043^{Aa}	0.0051^{Aa}	0.0032^{Bb}	158^{Ba}	133^{Ba}	217^{Aa}	687^{Ba}	578^{Ba}	942^{Aa}
	T	0.0047^{Aba}	0.0046^{Ba}	0.0058^{Aa}	147^{Aa}	151^{Aa}	119^{Ab}	638^{Aa}	655^{Aa}	516^{Ab}
N	Isolated effect *	PC1 = 0.0075^{b}	NT = 0.0069^{b}		PC1 = 95^{a}	NT = 101^{a}		PC1 = 409^{a}	NT = 436^{a}	
		PC2 = 0.0086^{a}	T = 0.0086^{a}		PC2 = 81^{b}	T = 80^{b}		PC2 = 350^{b}	T = 348^{b}	
		NV = 0.0073^{b}			NV = 96^{a}			NV = 417^{a}		
Ca	Isolated effect *	PC1 = 0.0056^{b}	NT = 0.0057^{b}		PC1 = 125^{a}	NT = 122^{a}		PC1 = 542^{a}	NT = 529^{a}	
		PC2 = 0.0065^{a}	T = 0.0065^{a}		PC2 = 107^{a}	T = 107^{b}		PC2 = 466^{a}	T = 465^{b}	
		NV = 0.0063^{ab}			NV = 111^{a}			NV = 483^{a}		

Means followed by the same letter are not significantly different by Tukey test at $P< 0.01$. Columns: Lowercase letters. Line: uppercase letters. PC1: plant cocktail 1, PC2: plant cocktail 2, NV: natural vegetation, NT: no-till, T: conventional tillage. *It was shown the isolated effects of the variables due to an absence of significant interaction among treatments.

incorporated and non-incorporated treatments, showing a slightly faster release in conventional tillage.

No significant interaction was observed among the types of treatments (Table 3). However, when evaluated separately, the types of plant cocktails and soil management showed a significant interaction for the Tukey test at 5% probability ($p<0.05$). In relation to the constant of decomposition (k), plant cocktail 2 with a mean of 0.0086 day^{-1} and treatments with T also with a mean of 0.0086 day^{-1} were highlighted. PC1 and NV take longer time to release 50% of nitrogen than PC2, with means of 95 days (k =0.0075 day^{-1}) and 96 days (k =0.0073 day^{-1}), respectively. As expected, the treatments in T system were those who take less time (80 days; k =0.0086 day^{-1}) to release half of the amount of N from the residues dry mass. To release 95% of the nitrogen from the residues it takes between 350 to 417 days, depending on the plant composition and soil management type (Table 3). Half of the nitrogen is released in the first 3 months after cutting the plant mixtures used as a cover crop. The amount of N released quickly in the early decomposition stage is associated with loss of water-soluble fractions of this nutrient (Zhang et al., 2016). Although the loss of N occurs by volatilization, leaching, etc., the amount of N that returns to the soil in the form of plant residues represents a considerable portion of the total N absorbed by plants in succession (Costa et al., 2012).

The cover crops cultivation promotes the increase of microbial P and labile P forms, in addition, the slow and gradual residue mineralization in the no-till system causes the release and redistribution of organic P forms, more stable and less susceptible to adsorption reactions (Malhi et al., 2018). Different from T system, the P decomposition rates (k) and times of 50 and 95% nutrients release were significantly different between PCs and NV (P<0.01) in NT. To release 50% of P in NT could range from 109 to 135 days for PCs and 167 days for NV. Treatments in T could range from 105 to 111 days to release 50% of P. The release of 95% of the P can take about 725 days (k = 0.0041 day^{-1}) in NT and 480 DAD (k = 0.0062 day^{-1}) in T for NV. Among the plant cocktails, the NPC1 takes 585 days in NT and 479 days in T to release 95% of P (Table 3).

The quantity of P released by NV, which was close to half of P accumulated by PC, is directly related to the average amount of this nutrient accumulated by NV biomass (Table 1).

The higher release of P during the initial period of decomposition is related to the loss of soluble P accumulated in the plant tissues vacuoles (Yang et al., 2017). Usually, the intensity and duration of rain are responsible for the amount of P that returns to the soil from the crop residues (Costa et al., 2012), but the phosphorus released have a tendency to be associated with the irrigation process than rainwater due to the incidence of low rainfall during this period.

Among the nutrients, K was the faster-released nutrient by plant residues, mainly in T system when the dry biomass residues were incorporated into the soil, which presented significant differences between the types of soil management ($p<0.001$). However, there were no significant differences among the treatments in T related to decomposition rates (*k*) and times of 50 and 95% of nutrients release ($p <0.001$). The residues required between 60 and 75 days (k =0.0093 day^{-1}) in NT treatments and around 42 days (k =0.017 day^{-1}) (for all the treatments) in T to release 50% of K. 95% of K was released between 260 and 324 days in NT treatments and between 179 and 181 DAD in T treatments (Table 3).

The highest speed of K release from plant residues can be attributed to the fact that K is an element that is not associated with any structural component of vegetal tissue, and found in ionic form with easily extracted from the plant tissue (Karthika et al., 2018) without necessarily having a biological decomposition and mineralization (Bernardes et al., 2010). Consequently, it is essential to reduce the implantation period of the successor culture to minimize the loss of K.

Different from the K, Ca has more difficulties to be mineralized by the fact that it makes part of the middle lamella of the cell wall constituents, forming one of the most recalcitrant components of plant tissues, and cofactor of some enzymes involved in the hydrolysis of ATP and phospholipids, and also secondary messenger in metabolic regulation (Karthika et al., 2018). Like N, no significant difference was observed among the treatments (Table 3). However, when evaluated separately, the types of plant cocktails and soil management showed a significant interaction for the Tukey test at 5% probability ($p<0.005$). To release 50% of Ca from dry biomass residues, the different cover crop could take 111 to 125 days. The treatments with NT took more time (122 days; k = 0.0057 day^{-1}) than T (107 days; k = 0.0065 day^{-1}) to release half of the amount of Ca from the residues dry biomass. To release 95% the plant mixtures (PCs and NV) residues could take a mean of 500 days (Table 3). On average, like P and N, plant residues takes approximately 3 months to release half of the amount of Ca accumulated. The fast release of Ca at the beginning of the process is related to the participation of this element with ionic compounds and water-soluble molecules (de Freitas et al., 2015).

Both 50 and 95% of Mg release from PCs residues were not significantly different between NT and T systems, except for NV ($P<0.01$) (Table 3). To release 50% of Mg, the PCs treatment could range from 133 (PC2, k = 0.0051 day^{-1}) to 158 days (PC1, k = 0.0043 day^{-1}). However, in NV, which was significantly different between soil management systems, the plant residues to release 50% of Mg could take 119 days (k = 0.0058 day^{-1}) in T and 217 days (k = 0.0032 day^{-1}) in NT. To release 95% of Mg could take about 942 days (k = 0.0032 day^{-1}) for NV in NT and 687 days (k = 0.0043 day^{-1}) for PC1 in NT. Similar to Ca, the higher Mg release early in the process is due to the participation of this element in ionic compounds and soluble molecules (Gransee and Führs, 2013).

NT treatments were significantly different from T treatments ($P<0.01$) and showed that the incorporation of plant residues increased decomposition and as a result the faster release of nutrients. To release 95% of nutrients from plant residues could take more than a year, except for K which could take about 324 days (k =0.0093 day^{-1}) when not incorporated in the soil, but 181 days (k =0.016 day^{-1}) when incorporated. This suggests that plant residues are still decomposed and nutrients are released along with the residue of the subsequent PC culture.

The order of release 50% of the nutrients accumulated in Plant Cocktails residues was K> N> P > Ca > Mg. 50% of the amount of N, P, Ca and Mg nutrients are released from the residues between the third to the fourth month after plant cocktails deposition, while K may take only 2 months to release into the soil. A management of successor culture can be done knowing the release time of the nutrients by the residues of the cover plants. The use of PCs could replace largely the need to supply nutrients via chemical fertilization, especially when it promotes synchronization between the nutrient released by plants residues with the demand of the successional crop.

Therefore, the PC1 and PC2 could be indicated for use as cover crops and green manure in similar agricultural areas, which demonstrated high potential to produce dry biomass and nutrients accumulation, different from NV that had lower dry biomass production that promoted less soil protection. In a no-till system, those plant mixture could minimize nutrient leakage and maximize nutrient cycling, interfaced with integrated weed and pest management options that require less agrochemicals (Rockström et al., 2017).

The lack of significant differences related to nutrient accumulation between PC1 and PC2 may be linked to the complexity of species selection to compose of the PC and the success depends heavily on interactions between components species, management practices available and environmental conditions (Lithourgidis et al., 2011). Tropical grasses usually have higher photosynthetic ability to grow and produce biomass (Taiz and Zeiger, 2013) whereas legumes can have relatively slower growth, however, with N incorporation function to the production system that may result in plants dominated by the slower species (Kaye and Quemada, 2017), disfavoring the balance in the green manure composition and damaging the desired benefits (Calvo et al., 2010).

The use of any evaluated PC is more efficient in nutrient accumulation and subsequent release into the soil than NV, considering that the amount of nutrient uptake by PC1 and PC2 showed no statistically significant differences. However, it can not disregard the potential of NV to accumulate nutrients and its recalcitrant character, which have the potential to cycle nutrients and maintain soil cover and that need to be better studied.

Cash crops in semi-arid regions, as melon, are characterized by the intense use of agricultural inputs, especially synthetic fertilizers which increase the cost production and environmental impacts. Therefore, PC used as green manure intercropped with melon can improve melon yield and soil quality, by nutrient cycling and biological nitrogen fixation. Thus, they were identified as positive effects in delivered nutrient to the melon when different leguminous and grass plants were cultivated as green manure, before melon production.

Accordingly, the cash crop intercropped with PCs as cover crops and green manure, with or without predominance of legumes and use of a no-tillage system, could be a technological strategy for adding biomass and nutrients to the soil, as well as increasing crop yields in semi-arid regions.

Conclusions

The data presented support the following conclusions:

(1) PCs had a DB production twice higher than NV, essential for adoption of NT in semi-arid region;
(2) There was a difference in residues decomposition from the surface deposited litterbags than those that were buried;
(3) DB production and nutrient accumulation by PC1 and PC2 had no significant differences;
(4) Nitrogen was the nutrient with the highest accumulation by PCs followed by K;
(5) The order of release 50% of the nutrients accumulated in PCs and NV residues was K> N> P > Ca > Mg and occurred less than the first four months;
(6) PCs could be indicated for use as cover crops and green manure in similar agricultural areas, which demonstrated high potential to produce dry biomass and nutrients accumulation and they could replace largely the need to supply nutrients via chemical fertilization;
(7) Use of PCs as cover crops and green manure, with or without predominance of legumes and use of a no-tillage system, could be a technological strategy in agroecosystems for nutrients cycling in semi-arid regions.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Socio-economic aspects related to feeding resources and practices in selected intensive dairy farms in Central Ethiopia

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Dairy cattle productivity is affected by many factors such as genetics, infectious diseases, husbandry and diet. Fodder resources, fodder availability and feeding strategies were assessed by means of questionnaires and interviews in seventeen dairy farms in Addis Ababa, Sendafa and Debre Zeit. Nutrient content was analyzed from hay sample. The farms were categorized as small, medium or large. Nutrient content, as well as milk production for the given rations were estimated per farm. Results showed that most farms were landless and grass availability was seen in only 1/3 of the farms. Purchased hay was of poor quality and needed to be bulked stored for the year. Storage capacity and quality varied with farm size. Supplemental feed varied by farm size and many of them were available only seasonally and were costly. With the exception of large farms, quality of fodder was poor in 70% of the farms, hence likely impacting animal productivity and health. Overall, constraints related to feeding and animal performance were: low fodder quality containing too little protein and energy, poor fodder storage condition, seasonal and costly fodder availability, poor feeding strategy, and lack of knowledge of small and medium farm owners regarding dairy husbandry and feeding management.

Key words: Ethiopia, fodder, dairy cattle, productivity, feeding management.

INTRODUCTION

The livestock subsector contributes 16.5% of the national Gross Domestic Product (GDP) and 35.6% of the agricultural GDP to Ethiopia's national economy and to the livelihoods of many Ethiopians as about 80% of the population depends on it (CSA, 2015; CIA, 2018). Ethiopia with 54 million heads, has the biggest cattle herd in Africa (CSA, 2015). However, nearly 99% are local zebu breeds (*Bos indicus*) that produce little amounts of milk (0.5 to 2 L/day) and have multi-purpose functions in small holder farmer's lives. High productive improved breeds of *B. taurus* type-predominantly Holstein Friesians and their crosses with local breeds are mainly found in

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urban and peri-urban livestock systems and make up 1% of the total cattle population (Leta and Mesele, 2014).

Ethiopia with 106 million people is the second most populous country in Africa with a growth rate of over 2.48%. With this rapidly growing human population and swift expansion of urban areas across the country, the demand for liquid milk and milk products is also increasing fast. In addition to its vital dietary aspects, milk production can be a major contribution to household economies and the economy at large. The Ethiopian Government plan, as stated in its Growth and Transformation Plan II, is to drastically increase over the next 5 years, the milk production and milk safety in the country (GTP II, 2016). The dairy industry is currently facing many challenges such as lack of veterinary services, fodder shortages, infectious diseases and poor breeding programs among other factors. Hence, the full potential of dairy animals is often not met. In average, improved dairy cows in the intensive dairy farming sector were shown to produce between 673 and 3700 liter milk per lactation as compared to over 5000 liter per lactation in Zimbabwe (Ayalew et al., 2015; Tadesse et al., 2010; Tadesse and Dessie, 2003; Ngongoni et al., 2006). Many factors have been shown to affect milk productivity, including infectious diseases such as Bovine tuberculosis (Hernandez and Baca, 1998; Boland et al., 2010). However, quantitatively and qualitatively adequate feeding of dairy animals remains a key parameter to maximize milk production and maintain animals in good health. Research on feeding strategies, fodder availabilities and constraints are scarce in Ethiopia.

The objectives of this study were 1) to describe qualitatively and quantitatively, the fodder used in selected dairy farms, 2) to identify constraints related to optimal fodder supply and 3) to assess whether fodder and feeding management has a potential impact on poor milk productivity and animal health.

MATERIALS AND METHODS

Study farms

This research is part of a larger study investigating the burden of bovine tuberculosis (BTB) in intensive dairy farms, and its potential impact on animal productivity. Seventeen farms that took part in this larger study were chosen for this fodder study based primarily on willingness of farm owners to participate, logistics and on having a geographical and farm size representation.

Investigated farms were all intensive urban dairy farms in the capital city Addis Ababa, Debre- Zeit and Sendafa (within a 50 km radius from the capital). The 17 farms were classified as small (1-10 cattle), medium (11-50 cattle) and large (>50 cattle). The study was carried out between July 2016 and December 2016. Cows were all hand-milked twice a day.

Study tools

Questionnaires and interviews

Farms were visited monthly and animal productivity parameters (fertility, milk, morbidity and mortality) were recorded as part of the BTB study. In addition, a semi-structured questionnaire was prepared in English, translated into Amharic, pre-tested and administered by the same person throughout the study. The questionnaire captured information on general husbandry, crops grown on farms and/or purchased, description of rations (qualitative and quantitative) given, feeding strategies and assessment of fodder and water quality as well as fodder sources and costs. Informal discussions/interviews were held with farmers, middlemen and fodder suppliers.

Personal observation

The research team observed how fodder was stored, prepared and fed to animals. Fodder was qualitatively assessed by touching, smelling and visualizing (e.g. presence of mold, freshness, length of fibers, size of grains) and categorized into very good-acceptable and very bad fodder quality. Storage facilities were inspected and listed depending on size, ventilation, sheltering from weather and rodents into 3 categories: very good, acceptable and very bad. Water sources, quality and quantity given were also observed directly. Fodder sources and markets in and around Addis Ababa were visited. Fodder transportation to farms was observed.

Field trial

A small scale demonstration was performed in one of the large farms that feed on elephant grass (*Pennisetum purpureum*). The usual practice is that farmers cut the grass when it reaches 3 m. During 5 days, 2 cows were given young elephant grass cut when they reached 1 m. Daily milk yields were recorded in these 2 cows earlier, during and after the trial.

Fodder analysis

Fodder from one selected farm was sent to UFAG Laboratories AG in Switzerland for analysis of their nutritional value.

Data management and analysis

Data was entered in Microsoft Excel spreadsheet and analyzed with STATA/IC 13.1 software. Descriptive analysis was conducted and results shown in tables and graphs. Chi square test was used to investigate statistical significance between groups such as farm size or geographical location. The nutrient value required by the animal and the amount of nutrients that the cow gets from the available rations was calculated using the methods described by Moran (2005). In short: the maximum dry matter intake was estimated using the following formula: Maximum dry matter intake (kg/day) = (120/NDF%)/(100 × LWT), where NDF is neutral detergent fibre and LWT is live weight. The daily energy, protein and fiber requirements of the dairy cows for maintenance, activity, pregnancy and milk production were calculated using the values given in the tables presented by Moran (2005). The energy, protein and fiber contents of the given diets, and hence the milk production potential, were estimated using forage and feed values from the literature.

Ethical clearance

This study received institutional (AHRI Ethics Review committee) and national ethical clearance (NRERC) with respective reference numbers P046/14 and 3.10/001/2015.

Table 1. Herd composition in the 17 intensive dairy farms (total cattle: 562)

Cattle category	Farm size	Mean % of total herd size	SD for the mean	Range	p-value
Adult females	Large	51.8	7.7	43.8-62.2	0.28
	Medium	52.8	12.5	31.6-69.2	
	Small	51.8	7.7	43.8-62.2	
	Overall	52.6	10.9	31.6-69.2	
Heifers	Large	34.3	10.5	21.6-47.4	0.45
	Medium	29.1	13.9	11.1-52.6	
	Small	31.9	6.4	25-37.5	
	Overall	30.8	11.8	11.1-52.6	
Calves	Large	12.8	3.1	8.8-16.2	0.37
	Medium	15.6	5.8	7.7-23.5	
	Small	15.3	16.8	0-33	
	Overall	14.9	7.6	0-33	
Adult bulls	Large	1	2.1	0-4.2	0.69
	Medium	2.5	4.3	0-11	
	Small	0	0	0	
	Overall	1.7	3.5	0-11	
Oxen	-	-	-	-	-

RESULTS

Dairy herd and land size

Table 1 shows herd composition in the study farm. Overall, adult dairy cows and heifers accounted for 83.4% of the herd size. The average landholding size was 5.7 ha per farm. However, there was a large disparity between the farms. Five out of 17 farms (29.4%) had neither grazing land for cows nor crop land, hence depended on purchasing all basic roughages. Cattle in these farms never left the indoor stables. The remaining 12 farms had land for their livestock but only 6 farms (35.3%) had actual grazing land for their animal while 1 farm was grazing his cattle off-farm, in neighboring public green spaces. The remaining 5 farms owning land, used an average of 0.3 ha for recreational purposes only. These areas were made of concrete or dirt and allowed animals to get fresh air and movements. Availability of grazing land was not related to farm size (p: 0.90) nor farm location (p: 0.45).

Grazing time, when available was variable, from a couple of hours daily to a couple of hours weekly. Grazing was also seasonal depending on the rainy seasons and thus grass availability. Grass was hardly available during the dry months (February-June).

On average, cattle density was 9 cattle per hectare area allocated to livestock (grazing and recreational areas). Considering only areas used for grazing and farms having grazing land, cattle density increased to 25 animals per hectare. Six farms (35.3%) had additionally other livestock. Two farms (1 medium and 1 large) (11.8%) produced crops for human consumptions (maize, teff, wheat and vegetables) and fed the animals seasonally with crop residues. All 4 large farms produced cattle fodder; 2 grew alfalfa and 4 grew elephant grass. Feeding of alfalfa and elephant grass was intermittent, every 3 weeks and only for selected animals (the best cows).

Fodder and water rations

The 4 most prevalent fodders fed on were hay, wheat bran, cotton seed cakes and brewery by-products. Types of fodder however, differed by farm size (Table 2). Overall, large farms provided a larger variety of fodder types than medium and small farms (Figure 1) and provided animals regularly with fresh roughages such as fresh grass, alfalfa and elephant grass, grown seasonally on-farm. Two medium farms in Addis Ababa feed animals on green Enset leaves (*Ensete ventricosum*) collected from markets. Only 3 farms (17.6%) supplemented the animal diet with purchased commercial concentrates. Farms used home-made supplementary feeds that were either locally available (permanent or seasonal) and/or affordable. On-farm crop residues were found in 3 farms only whereas the remaining 14 farms had to purchase all supplements. Availability, source and cost of the different fodders are shown in Table 3.

Provision of water

Mean quantity of daily water given to animals varied by

Table 2. Type of fodder given by farm size. Percentages are shown in brackets.

Fodder	Small farm (N=3)	Medium farm (N=10)	Large farm (N=4)	p-value
Grass	1 (33.3)	5 (50)	4 (100)	0.140
Alfafa	0 (0)	0 (0)	2 (50)	0.025
Elephant grass	1 (33.3)	0 (0)	4 (100)	0.001
Enset	0 (0)	2 (20)	0 (0)	0.452
Wheat bran	3 (100)	10 (100)	4 (100)	-
Nough	1 (33.3)	6 (60)	4 (100)	0.168
Brewery by-products	1 (33.3)	8 (80)	1(25)	0.103
Pea straw	1 (33.3)	7 (70)	0 (0)	0.05
Wheat straw	0 (0)	4 (40)	1 (25)	0.401
Maize	0 (0)	0 (0)	2 (50)	0.025
Molasses	0 (0)	1 (10)	3(75)	0.02
Concentrates	1 (33.3)	2 (20)	0 (0)	0.496

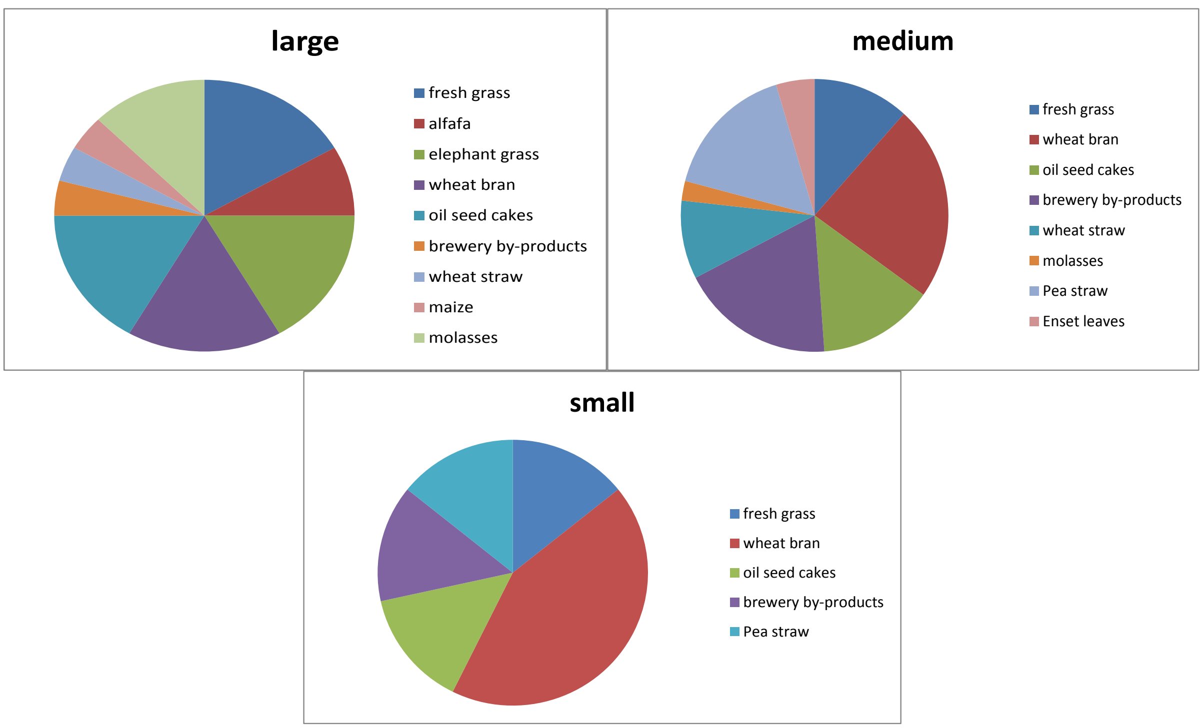

Figure 1. Fodder variety by farm size

farm and farm size with small farms providing the least water amount (Table 4). Large farms generally provided water *ad libitum,* whereas in small and medium farms, animals were watered with buckets twice a day. Additional water supplies came from watering troughs in the outside areas in 5 farms. Supplements such as crop residues, oil seed cake, maize, bran, brewery by-products were mixed with water before feeding.

Tap water provided the regular watering in 16 farms (94%), whereas 1 farm (5.9%) additionally purchased water, whereas another farm entirely relied on purchasing water. Two farms (11.8%) had underground water sources and 3 farms (17.6%) collected rain water. Water quality was ranked as very good in 2 farms (11.8%), both being large farms, good in 13 farms (76.5%) and bad in 2 farms (11.8%). The latter was in one large and one small farm.

Table 5 shows the results of nutrient content analysis of hay. Overall, nutrient values (CP, crude fat and glucose) and digestibility of organic matter were well below the reference range for quality hay, whereas crude fiber was well above the ideal range. These results were

Table 3. Availability, source and cost of fodder

Fodder	Type	No. (%)	Source	Location	Availability	Cost range (birr per quintal =100 kg)
Roughages	Fresh grass	8 (47)	On-farm/neighborhood		Seasonal	
	Hay	17 (100)	Purchased Produced (N=1)	Sendafa, Sululta	Yearly	300-400
	Enset leaves	2 (11.8)	Transport cost only	Local market	Yearly	100 per truck
Cultivated grass	Alfalfa	2 (11.8)	On-farm		Seasonal	
	Elephant grass	4 (23.5)	On-farm		Seasonal	
Crop residues	Wheat straw	6 (35.3)	Purchased On-farm	Mainly Sululta	Yearly Seasonal	80-90
	Pea straw	7 (41.2)	Purchased	Mainly Debre Berhan	Seasonal	120-300
	Vegetables (tomato, salad, cauliflower, cabbage)	2 (11.8)	On-farm		Seasonal	
Industrial by-products	Wheat bran	17 (100)	Purchased	Addis Ababa, Bale, Debre Zeit, unknown	Yearly	300-520
	Oil seed cake (cotton and noug)	11 (64.7)	Purchased	Addis Ababa, Adama, unknown	Yearly	400-700
	Brewery by-products	10 (58.8)	Purchased	Addis Ababa, Sebeta, Debre Birhan	Yearly	130-225
	Molasses	3 (17.6)	Purchased	Sugar factories		
Other	Maize residues	2 (11.8)	On-farm		seasonal	
	Purchased concentrates	3 (17.6)	Purchased	Debre Zeit; Special animal fodder shops	yearly	650- 800
	Minerals/Vitamins	10 (58.8)	Purchased	Special animal fodder shops	yearly	500-1000
	Salt	17 (100)	Purchased	Local shops	yearly	400-600

Table 4. Cattle watering by farm size

Farm Size	Mean liter/cow /day	SD	Range liter/day	Watering technique	Frequency
Small	23.3	11.5	10-30	Bucket	Twice/day
Medium	42.5	20.3	20-75	Bucket	Twice/day
Large	85	19.1	60-100	Individual cow bowl	*Ad libitum*

comparable to straw in Switzerland.

Nutrients level in the food ration and milk production potential

Cows were milked by hand twice a day. The average daily milk yield (DMY) reported was 11.24 L, which is comparable to values reported in other studies: in the central highlands (Bereda et al., 2017), Arsi zone (Solomon, 2010) and Amhara region (Belete, 2006).

Table 6 shows the nutrient value received on average by each cow on each farm of the study. Based on the estimated energy content of the rations, the milk production potential (MPP) was calculated. The maximum MPP was 14.5 liter per day and is in general below the average daily collected milk reported by the farmers. Moreover, many rations were not balanced, with a crude protein content below the recommended 14 to

Table 5. Laboratory analysis of hay collected from a selected study dairy farm (UFAG Laboratories AG, Sursee, Switzerland)

Nutrient	Result value	Ideal reference range
Dry Matter (DM)	905 g/kg	850-950 g/kg
Crude Ash (CA)	79 g/kg DM	80-120 g/kg DM
Crude Protein (CP)	45 g/kg DM	110-190 g/kg DM
Crude Fiber	365 g/kg DM	210-260 g/kg DM
Crude Fat	17 g/kg DM	20-35 g/kg DM
Digestion coefficient of organic matter	51.3%	75-79%
Glucose	38.8 g/kg DM	70-150 g/kg DM

Table 6. Nutrient values of fodder ration in the 17 farms by farm size and Milk Production Potential (MPP)

Farm size	Dry matter (Kg)	Crude Protein (Kg)	Crude Fiber (Kg)	Metabolic Energy (MJ)	Crude Protein (%DM)	Crude Fiber (%DM)	Calculated MPP*	Orally Reported milk production
Large	16.444	3.10292	4.17176	129.054	18.8696	25.3695	13.6	15
Large	15.666	1.70849	4.15284	122.7325	10.9057	26.5086	14.5	18
Large	11.52	1.28857	2.69469	94.7815	11.1855	23.3914	9.5	14
Large	15.165	2.33533	4.03548	114.9775	15.3994	26.6105	13.1	15
Medium	12.799	1.6742	3.23064	115.0785	13.0807	25.2413	8.5	13
Medium	10.627	1.86171	2.58492	86.2975	17.5186	24.3241	8.1	10
Medium	9.587	1.11555	2.34065	104.9735	11.6361	24.4148	8.4	12
Medium	8.3	1.19845	2.10165	72.592	14.4392	25.3211	5.7	10
Medium	9.85	1.35275	2.50662	87.425	13.7335	25.4479	8.4	9
Medium	12.01	1.83371	3.14929	90.398	15.2682	26.2222	8.8	15
Medium	10.515	1.25785	2.95481	78.1675	11.9624	28.1009	6.7	7
Medium	9.325	1.48285	2.53978	71.1425	15.9019	27.2362	5.5	12
Medium	7.43	0.857	2.09346	53.39	11.5343	28.1758	2.4	9
Medium	8.32	0.9275	2.29569	64.515	11.1478	27.5924	4.3	6
Small	5.438	0.64368	1.47964	39.6413	11.8367	27.2092	0	10
Small	7.02	0.85325	1.77827	65.4375	12.1546	25.3314	4.5	8
Small	12.7045	1.34024	3.94604	72.82625	10.5493	31.0602	5.7	8

*MPP calculated from ration, without considering needs for pregnancy

18% for early and mid-lactation (Moran, 2005)

Feeding strategies

Almost every farm fed their dairy cows differently. Industrial by-products were mixed with water before feeding their cows. However, the frequency and freshness of the mix differed. Some farms prepared the mix once weekly and fed every day from it. Others prepared the mix daily, others every 2 days. Some of the farms added straw to the mix, others did not.

The feeding sequence during the day differed by farm as shown in Table 7. 44% of the farm milked in the morning before feeding. The chronology between concentrate and hay feeding differed: 57% fed concentrates before feeding hay or other forages.

All farms except one allowed the animal a dry period and stopped milking. But only 30% of the farms made a diet change to cover the nutritional needs of dry cows adequately.

Demonstration result

Two cows from a selected farm were fed with 10 kg/day/cow of either matured or young elephant grass (EG) twice a day for 5 days. The trial started with 5 days of feeding on matured elephant grass, followed by 5 days of young elephant grass and again 5 days of mature

Table 7. Chronology of daily feeding activity

Farm size	Feeding activity							
Large	Milking	Concentrate	Hay	Grass	Hay	Milking	Concentrate	Hay
Large	Milking	Brewery by product	Straw	Concentrate	Vegetables	Brewery by-products	Concentrate	Milking
Medium	Hay	Milking	Concentrate	Hay	Milking	Concentrate		
Medium	Milking	Concentrate	Water	Hay	Milking	Concentrate	Hay	
Medium	Hay	Milking	Concentrate	Water	Enset	Milking	Hay	Water
Medium	Milking	Concentrate	Hay	Grazing	Milking	Concentrate	Hay	
Medium	Milking	Hay	Water	Grazing	Milking	Water	Hay	
Medium	Hay	Milking	Concentrate	Grazing	Hay	Concentrate	Milking	Hay
Medium	Milking	Concentrate	Hay	Water	Milking	Concentrate	Hay	Water
Medium	Concentrate	Milking	Hay	Water	Straw	Milking	Hay	Water
Medium	Concentrate	Milking	Hay	Water	Straw	Milking	Hay	Water
Small	Milking	Concentrate	Hay	Water	Hay	Milking	Concentrate	Hay
Small	Concentrate	Milking	Hay	Water	Grazing	Milking	Hay/grass	
Small	Hay	Milking	Concentrate	Water	Hay	Concentrate	Water	Milking

Table 8. Impact of feeding young elephant grass (*Pennisetum purpureum*) on milk production (a demonstration)

Animal	Milk yield (lt/day) while feeding mature EG	Milk yield (lt/day) while feeding young EG	Milk yield (lt/day) while feeding mature EG
Cow 1	22.33	23.6	23.2
Cow 2	21.9	22.4	21.8

Challenges related to fodder

Quality

Fodder quality was not assessed by farmers upon purchase. Over half of the farms (N=9; 53%) had fodder of bad to very bad quality (e.g. too old, containing mold) (Figure 2), which included 3 out of the 4 small farms (75%). There was a statistical significance of fodder quality by farm size (p: 0.015). Only large farms had good to very good quality fodder (N=4; 23.5%).

Availability and storage place

Most fodder availability varied with seasons. Fresh grass was mainly available during and after rainy seasons. Urban and peri-urban dairy farms purchased hay once a year after harvest in November-December directly from small holders in the countryside but usually through middlemen who adjust the prices as they wish. Hay is usually stored for an entire year. Farms are often low on hay towards the end of the year. Straws and crop residues follow harvesting patterns, being seasonal. Industrial by-products such as oil seed cakes and brewery by-products are found all year round with some exceptions and are purchased on a regular basis (1-2 x per month) hence not requiring long storage time.

There was statistical difference in storage facility quality and farm size (p: 0.001). While all large farms had adequate storage place and facilities (N=4; 23.5%), the study showed that small and many medium farms lacked space and could not store adequately and safely (e.g. access to weather and rodents) for long period of times. The storage quality was assessed as excellent in all large farms, whereas 35.3% of farms (medium and small) had bad quality storage. None of the medium and small farms had good storage capabilities.

Price of fodder

Table 3 shows the price range of the available fodders. Most farms relied entirely on purchasing fodder (roughages, by-products and concentrates). Prices fluctuated with season and thus availability, as well as holidays, use of middlemen who can adjust their price as they wish and transportation. The study found that middlemen are the major reason for the price fluctuation. There is no fixed market price for most of the fodder.

Ownership and knowledge of farmers

Ownership of farms varied: 1 large farm was a government farm, 2 large farms were private-NGO type,

Figure 2. Moldy hay.

2 medium farms were private shared farms with several owners, and 12 were private owners. Ownership type did not play any statistical role. Overall, 11 farmers (64.7%) received their farm knowledge from their family and through own experience accumulated over the years; this included all small farms and the majority of medium farms; 4 owners (23.5%) had an educational background at certificate or diploma levels relevant to farm management. These were all 4 large farms. Two farms (11.8%) had their knowledge from their family but attended addition courses provided occasionally by the kebele on farm husbandry/management. There was a statistical significance between farm size and level of knowledge of owners (p: 0.001).

DISCUSSION

This study of husbandry, feeding resources and feeding practices in dairy farms in and around Addis Ababa highlighted some of the challenges and bottlenecks to improved animal productivity and health, namely i) availability of fodder, ii) fodder quality and iii) feeding management.

Dairy cows require basal roughages (grass and hay) as bulk diet and additional fodders high on protein or energy (concentrates, supplementary feeds) (Van Soest, 1982). In this study, grazing and/or fresh grass was available in only a third of the farms and 2/3 of the farms never fed fresh grass. Grazing and grass availability was season dependent, available during and after rainy season but hardly available during the dry season (March-June). Large farms cultivated alfalfa (*Medicago sativa*) and/or elephant grass (*Pennisetum purpureum*) but fed them only intermittently to their animals (every 2-3 weeks) and only to selected animals. As a consequence, all dairy farms in the study relied entirely on purchased hay for their main basal roughages. Hay was purchased annually and stored for the entire year on-farm, hence requiring adequate storage facilities. Only the large farms in the study had sufficient good quality and spacious storage facilities. The nutrient content analysis of hay showed that it was comparable to straw quality rather than good quality hay and the hay was moldy and/or old in 70% of the farms. Harvesting stage of the plant, drying duration as well as storage duration are known to affect the nutrient content. Plants at a younger growth stage for instance, contain less fiber and more nutrients (Lounglawan et al., 2014; Tilahun et al., 2017). Although, the small on-farm demonstration should be interpreted with caution since it is not statistically representative, it showed that milk production increased between 0.5 and 1.3 L/day per animal within a period of 5 days if fed younger elephant grass instead of the usually cut mature elephant grass. Farmers producing, harvesting and selling hay have poor knowledge on hay quality and grass is harvested and dried when very mature, hence losing important nutrients. In addition, the long storage time (almost a year) on-farm and contact with weather (sun and rain) add to the loss of nutrients. Rural land in Ethiopia is increasingly converted into crop land to feed the growing human population, and good grass lands are declining dramatically (Tschopp et al., 2010; Amsalu and Addisu, 2014). Grass is often harvested along roads or terrain that is not suitable for crops, hence likely to have an impact on grass quality (personal observation). In recent years, more attention has been given by the Government to fodder production in areas in the country such as Afar (personal communication).

Enset (*Ensete ventricosum*), a monocarpic short-lived drought-tolerant perennial plant is used as a food source for humans and livestock in parts of the country (Alemayehu et al., 2001; Nurfeta et al., 2008). The leaves are used as wrapping material and have high protein content (13%) (Tolera and Said, 1994; Mohammed et al., 2013). They contain more calcium than hay, have a higher digestibility than grass and have a net energy comparable to barley (Van der Honing and Steg, 1984). Enset leaves-as green forage, can be found all year round for free in markets and farmers only have to pay for transportation (100 birr (5 USD) for the truck). Despite this readily available cheap fodder source in Addis markets, only 2 farmers fed their animals with it.

Supplementation of additional feeds to cover protein and/or energy needs varied by farm size (Figure 1) with the smallest variety found in small farms. The bulk of these feeds are “homemade” with locally available feed and are often seasonal and costly (Table 3). The major supplemental feed were wheat bran, cotton and nough seed (*Guizotia abyssinica*) cake, brewery by-products and straw (pea, wheat). Cotton and nough seed cake are high on energy and protein and were given by 64.7% of the farms. The use of molasses is often encouraged as it provides energy necessary for microbe activity in the rumen and improves palatability of rations (Van Soest, 1982). In this study, only 4 farms provided their animals with molasses; 3 of them were large farms. Molasses are available from sugar factories that are usually found in locations at lower altitudes (e.g. Adama and Metahara). This requires some logistics since the farmer has to drive there to collect the molasses.

An estimation of the milk production potential (MPP) of the rations distributed to the dairy cows (Table 6) indicated that the maximum MPP was 14.5 L. Farmers generally overestimated the daily milk production when reporting in interviews. Moreover, many rations were not balanced, they were too high on fiber, with a crude protein content below the recommended 14 to 18% for small breeds to allow proper rumen function (Van Soest, 1982) for early and mid-lactation, respectively (10 farms; 58.8%). However, more recent research indicates that the CP content of the ration can be decreased as low as 12% without affecting milk production in low producing dairy cows (Aschemann et al., 2012). Nevertheless, 7 farms (41%) were below the 12% hence their diet having a likely impact on milk production. MPP was linked with farm size. MPP using the rations given showed a mean 12.67 L/day/animal (SD=2.19) for large farms, a mean of 6.68 L/day/animal (SD=2.16) for medium farms, and a mean 5.7 L/day/animal (SD=3) for small farms. Large farms were shown to have better feeding practice and feeding resource which was reflected in the higher MPP.

Milk performance is tightly linked to fertility performance. Fertility is also a high energy demanding process. Feeding animals inadequately will lead to fertility problems (poor heat, poor conception rate) as observed in most of the study farms (data not shown). The ration given in the study showed clearly a lack of energy and protein for proper milk production and fertility performance.

Performance and health of a dairy cow depend very much on adequate rumen function. The latter is affected by various factors such as fodder type and quality, frequency of feeding (the more often an animal is fed, the least pH variation is seen in the rumen), the size of the grains and fibers (too small particles lead to acidosis), and the feeding sequence (hay before concentrates) (Slyter et al., 1976; Yang et al., 2001; Le Liboux and Peyraud, 1999; Macleod et al., 1994). The study showed overall that, farmers fed between 3 and 6 meals per day (as compared to the recommended 12 meals a day or *ad libitum* feeding for dairy cows) and over half of the farmers fed concentrates before feeding hay/forage. This feeding strategy likely leads to poor rumen function with high pH variation, and risk of acidosis, which ultimately impacts on milk performance and health in general.

All small and medium farms were under-watering their animals. A dairy cross needs about 45-50 L/day for maintenance and 1.5 L extra for each liter milk produced (Murphy, 1992). An animal that produces about 10 L/day as in our study would require at least 60 liter water per day. In average, small and medium farms gave 23.3 and 42.5 L/day, respectively. This severely impacts on milk production and risk of chronic dehydration. The reason lies probably on the lack of knowledge from farmers on animal requirements, existing shortage of water, and bucket drinking logistics which is time consuming and hard work for staff.

All small farms and some of the medium farms showed the poorest animal management and husbandry. Knowledge on the physiology of the rumen and the impacts of fodder types and feeding strategies is crucial in order to keep dairy animals healthy and meet their productivity potential. This study showed that this knowledge is lacking in small and medium farms. This is ultimately reflected by the level of training received. This study showed that all small farms and most of the medium farm owners have had no training in dairy farming. Their knowledge came from own experience obtained over the years and knowledge passed down by family members. In contrast, all large farm owners/ managers had educational backgrounds at certificate or diploma level relevant to dairy farm management. Kebeles are regularly offering training courses for farmers. However, only 2 farmers attended some of these courses.

Since fodder availability is a major constraint due to seasonal availability and high costs, it is even more important that farmers manage the feeding by supplying all nutritional requirements to maintain animal health and performance according to animal outputs such as maintenance, growth, lactation and reproduction optimally in a most cost-efficient way. Lactation can be divided into 3 periods (Tyrell, 2005; Broster and Strickland, 1977; Johnson,1984): a) Lactation peaks during the first 100 days (negative energy balance), requiring optimal feeding for good rumination and high protein supply (17 to 19%) for milk production; b) lactation plateaus that starts decreasing in mid-lactation phase (100 to 200 days). The aim is to keep the production high as long as possible. Dry matter intake is to be maximized with now lower protein supply (15 to 17%); c) decreased lactation to termination, with decreased feed intake. In this phase, protein and energy supply is no more critical and cheap rations can be provided. Hence, targeted feeding that focuses on the three first lactation months can be more cost-effective, and will provide a good milk production and better fertility. Under-nutrition in the early phase will negatively impact on the rest of the lactation (Lukuyu et al., 2011). In Kenya, feeding high concentrated feed in early lactation was shown to increase the milk production by 20% (Romney et al., 2000). Whereas, keeping the same feeding regime throughout the lactation, as seen in this study, particularly in the last lactation phase, will be too costly for the animal need and a waste of scarce feeding resources.

Conclusion

Urban dairy farms are facing multiple challenges to maintain and improve animal productivity. This study showed that poor feeding management (poor feed resources, poor fodder quality which lack protein and energy, and wrong feeding strategies) is likely a key factor for poor milk productivity, fertility and health problems. In addition, poor storage quality (e.g. accessible to rain, rodent urine and feces) led to further deterioration of fodder quality. The contamination of milk and dairy feeds by toxins due to poor feed storage and mold accumulation, is a major problem in the Greater Addis Ababa milk shed with potential public health impacts (Yitbarek and Tamir, 2013; Gizachew et al., 2016). Except large farms, knowledge on dairy husbandry and management was lacking. Training of small holder dairy farmers is crucial so that they can assess good quality forages on purchase, optimize feeding rations per lactation stage so as to maximize milk productivity in early lactation and save costs during late lactations. This strategy is even more relevant in the context of scarce, seasonally dependent and costly fodder as seen in Ethiopia. Strategies should be developed to overcome the issue of seasonal availability of fodder, their high costs and poor quality so as to develop a good quality fodder value chain or on-farm forage production. Hay farmers should be trained on production of good quality hay.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Efficiency of *Trichoderma asperellum* UFT 201 as plant growth promoter in soybean

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Filamentous fungi of the genus *Trichoderma* are known for their activity as plant growth promoters. The objective of this work was to evaluate the efficiency of the *Trichoderma asperellum* UFT 201 strain as a plant growth promoter in soybean. The ability of phosphate solubilization, indole acetic acid synthesis and the effect on soybean plant growth under greenhouse conditions were evaluated in four experiments. *In vitro* and *in vivo* analyzes were performed. Plant biomass characteristics such as shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM) were evaluated. *T. asperellum* UFT 201 showed a significantly higher concentration (p <0.05) with a phosphate solubilization capacity of 67.8% higher than the positive control treatment (*Trichoderma harzianum*). The production of indole acetic acid (IAA) by *T. asperellum* UFT 201 was 26.7% higher than the positive control. The effect on the biomass treated by *T. asperellum* UFT 201 was higher (p <0.05) than the positive and absolute controls. Thus, inoculation by *T. asperellum* UFT 201 showed high efficiency as a growth promoter in soybean.

Key words: Phosphate solubilization, indole acetic acid, growth promoter, *Glycine max.*

INTRODUCTION

Soy (*Glycine max* L.) is one of the most cultivated grains in the world. For the cultivation of soybean and any other crop, some factors must be considered, being the choice of healthy seeds and the performance of the seed treatment, which aims at maintaining the quality of the plants, that could allow the expression of the maximum potential of the crop (Cunha et al., 2015).

The plant growth promotion by soil microorganisms can be performed by direct and indirect mechanisms. The direct mechanisms can be the production of hormones or another substance analogous to them, which influence the growth or development of the plant (Machado et al., 2011; Zeilinger et al., 2016; Gonçalves et al., 2018), or the supply of their nutritional needs by solubilization of phosphates (Contreras-Cornejo et al., 2016). On the other hand, the indirect mechanisms can be by the action of microorganisms through the suppression of pathogens (Silva et al., 2011; Gava and Menezes, 2012; Saravanakumar et al., 2016).

Various soil microorganisms such as fungi can solubilize different forms of inorganic phosphates. Fungi have been reported as phosphate solubilizers in various

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Table 1. GenBank access code for *Trichoderma asperellum* UFT 201.

Isolate	Species Identification	GenBank access	Similarity	Reference
UFT 201	*T. asperellum* GJS 04-217	DQ381958	99%	Samuels et al. (2010)

works (Kapri and Tewari, 2010). Filamentous fungi of the genus *Trichoderma* have been the most commonly studied microorganisms as biological control agents of plant diseases and they also have activity as plant growth promoters (Santos et al., 2010; Machado et al., 2011). The influence of *Trichoderma* species on plant development is broad, which includes beneficial effects on seed germination, seedling emergence, grain growth and yield (Chagas et al., 2016). Kapri and Tewari (2010) highlighted the potential of phosphate solubilization by *Trichoderma* spp. isolates in culture medium. They evaluated the concentrations of soluble phosphate (μg mL^{-1}) and the significant increase in growth parameters of chickpea (*Cicer arietinum*) in greenhouse trials. Similar studies were done for crops such as cowpea according to Chagas et al. (2015).

Nowadays, the use of growth-promoting micro-organisms in plants to increase agricultural production will probably be one of the most important tactics in the world. This is due to the emerging demand to reduce dependence on chemical fertilizers and the need to develop sustainable agriculture. The production of low cost bioinoculants formulated with plant growth promoting microorganisms such as *Trichoderma* species is an alternative to reduce the environmental risks caused by inadequate and sometimes excessive use of inputs and pesticides.

Thus, the objective of this work was to evaluate the efficiency of the *Trichoderma asperellum* UFT 201 in phosphate solubilization, indole acetic acid synthesis and as a soybean growth promoter.

MATERIALS AND METHODS

Location of experiments

The experiments were conducted in a laboratory and greenhouse at the experimental station of the Federal University of Tocantins, Campus Gurupi, located in the southern region of Tocantins State, Brazil. The geographical coordinates of the experimental station correspond to 11°43'45 "S and 49°04'07"W, with an average altitude of 280 m.

Trichoderma strains and characterization

The *T. asperellum* UFT 201 strain was obtained from the Microbiology Laboratory of the Federal University of Tocantins, Campus Gurupi. This strain was isolated from Cerrado soil in Tocantins. A preliminary identification was made according to the morphological characteristics based on specialized bibliography and with the aid of an optical microscope. Then, the genetic characterization was performed by sequencing the TEF (translation elongation factor) region and identified by the access codes in GenBank (Table 1). This identification was carried out by Instituto Biológico de São Paulo (Brazil).

Trichoderma harzianum CIB T23 strain was used as a positive control in laboratory experiments and in the second greenhouse experiment (access GenBank EU279989) (Hoyos-Carvajal et al., 2009). This strain was used considering that it is the most commonly used strain in commercial products with active microorganism based on *Trichoderma.* Also, the commercial bioinoculant ICB Nutrisolo (BioAgritec Ltda), based on *T. harzianum*, *T. asperellum* and *T. koningiopsis* (concentration of 1 x 10^{11} CFU mL^{-1}, liquid formulation, recommended dose of 300 mL ha^{-1}) was used in experiments three and four under greenhouse conditions. This bioinoculant is registered as a plant growth promoter (MAP Register in RS 12734/10000-4) for lettuce (*Lactuca sativa* L.).

Phosphate solubilization ability

The strains of *T. asperellum* UFT 201 and *T. harzianum* CIB T23 were first cultured in petri plates containing PDA medium (HiMedia: 200 g potato, 20 g dextrose, 15 g agar, 1 L distilled water) at 25±2°C 12 h photoperiod for seven days. Discs of approximately 8.0 mm diameter containing mycelium and spores were removed from the colonies and transferred to Erlenmeyer flasks (250 ml) to evaluate their phosphate solubilization potential *in vitro* in modified NBRIP medium containing the following ingredients (g L^{-1}): glucose, 10.0; $MgCl_2.6H_2O$, 5.0; $MgSO_4.7H_2O$, 0.25; KCl, 0.2; $(NH_4)_2SO_4$, 0.1. 50 ml of K_2HPO_4 (10%) and 100 ml of $CaCl_2$ (10%) were added to the medium to form an insoluble precipitate of calcium phosphate ($CaHPO_4$).

The quantitative estimation of phosphate solubilization was performed in triplicate in a completely randomized design. On the seventh day of microbial growth, the determination of the soluble phosphorus (P) concentration was performed by the colorimetric method described by Murphy and Riley (1962), by subtracting the soluble P contained in the treatments by the contained in the control sample (phosphate culture medium and without inoculum). 1.0 ml of the reagent, 0.5 ml of the filtered sample and 3.5 ml of ultrapure water (Biosystem) were used for evaluations of each sample. After 20 minutes of reaction, the soluble P was quantified in a spectrophotometer at the wavelength of 725 nm by measuring the absorbance. The standard curve was made from monobasic potassium phosphate and the concentrations calculated in μg mL^{-1}.

Synthesis of indole acetic acid (IAA)

The *Trichoderma* colonies were transferred to Erlenmeyer flasks (150 ml) containing 25 ml of potato dextrose broth with addition of L-tryptophan (100 mg L^{-1}). The indole acetic acid (IAA) production was performed for 7 days on a rotary shaker (100 rpm) at 26 ± 2°C. The fungal biomass was separated by centrifugation (12.000 rpm for 15 min). Colorimetric analysis of IAA was performed using a portion of the Salkowski reagent (0.5 M L^{-1} $FeCl_3$ + 35% $HClO_4$), two parts (2 ml) of the fungal supernatant and filling the final volume to 5 ml with ultrapure water (Biosystem). After qualitative verification of IAA in the supernatant (pink staining after 25 minutes of reaction at 26±2°C in the dark), the phytohormone was quantified spectrophotometrically at 530 nm. Concentrations were calculated from a standard curve of IAA (0 to 10 μg mL^{-1}) (Cattelan, 1999).

Table 2. Chemical analysis of soils and organic matter of greenhouse experiments.

Experiment	pH	P	K	Al^{3+}	H+Al	Ca^{2+}	Mg^{2+}	SB	T	V	MO
	H_2O	mg dm^{-3}		--------------cmol$_c$ dm^{-3}----------						%	g.dm^{-3}
1	5.6	1.7	17.4	0.0	3.7	1.7	0.6	2.4	6.1	39.4	28.1
2	5.6	2.7	14.4	0.0	3.7	1.7	0.5	2.4	6.1	39.4	28.1
3	5.4	2.7	15.0	0.0	3.5	1.9	0.6	2.5	6.5	33.4	29.5
4	5.4	5.8	17.0	0.0	5.5	1.8	0.7	2.7	6.1	33.3	25.6

Chemical attributes of depth 0-20 cm; pH in water - ratio 1: 2.5; P and K - Mehlich extractor 1; Al^{3+}, Ca^{2+} and Mg^{2+}- KCl extractor (1 mol L^{-1}); H + Al - SMP Extractor; SB = Sum of Exchangeable Bases; T = Cation exchange capacity at pH 7.0; V = Base Saturation Index; and OM = organic matter (oxidation: Na2Cr2O7 4N + H2SO4 10N).

Greenhouse experiments

After the phosphate solubilization and IAA synthesis tests, the ability of *Trichoderma* strains as promoters of soybean plant growth under greenhouse conditions was evaluated in four experiments. Positive controls (commercial *Trichoderma* bioinoculants) were used. The experiments were carried out in black plastic pots of 1.7 L. The pots were filled with soil collected in crop areas at the experimental station of the Federal University of Tocantins, Campus Gurupi.

Soil analysis and fertilization

A sample composed of each soil in the different experiments was collected before planting and the chemical characterization of organic matter (OM) was carried out at the Soil Laboratory of the Federal University of Tocantins (Table 2). Soil samples were classified as Dystrophic Red-Yellow Latosol (sieved) and medium texture. It presented the following granulometric characteristics: experiment 1 (72.3% sand, 8.2% silt and 19.5% clay), experiment 2 (70.1% sand, 7.2% silt and 22.7% clay), experiment 3 (72.3% sand, 8.2% silt and 19.5% clay) and experiment 4 (70.5% sand, 7.2% silt and 22.3% clay) (EMBRAPA, 2009). The soils were fertilized using a minimum dose rate of 250 kg ha^{-1} of formulation 05-25-15 in all experiments.

Preparation of inoculants and soil inoculation

The strains of *Trichoderma asperellum* UFT 201 and *T. harzianum* CIB T23 were grown and multiplied on petri dishes containing PDA culture medium. Then, the inoculants were transferred to sterilized millet grains. The millet was weighed, and distilled water was added. Afterwards the grains were transferred to polypropylene bags (300 g of millet / bag with 300 ml of distilled water) and autoclaved at 121°C for 1 h. After cooling, six 5 mm diameter discs containing mycelia, *Trichoderma* spores and PDA medium were inoculated into the millet with the aid of sterilized forceps. The polypropylene bag was opened in laminar flow camera.

The bag was incubated in camera type Biochemical oxygen demand (B.O.D.) with controlled temperature and light at 25°C and 12 h photoperiod for 14 days. Every two days the millet was stirred to facilitate the gas exchange, the breakdown of the mycelial aggregates and the increase of sporulation. Some millet bags were incubated without *Trichoderma* inoculation to be used in vessels with the absolute control treatment. After 14 days of incubation, the millet colonized with the *Trichoderma* strains were weighed at a ratio of 30 g per 1.7 L pot. Thus, the millet was mixed with the sifted soil and placed in the pot. The colonization was carried out for 7 days for subsequent planting of the soybean. Millet without inoculation by *Trichoderma* was added to the soil in the absolute control.

Samples of 1 g of millet colonized by *Trichoderma asperellum* UFT 201 and *T. harzianum* CIB T23 were collected for evaluation of spore counts in Neubauer chamber. Data analysis was done by means of the *Trichoderma* spore counts, where they had a concentration of 2 × 10^8 CFU $g^{-1}$for the test strain *T. asperellum* UFT 201 and 1.8 × 10^8 CFU g^{-1} for *T. harzianum* CIB T23 as standard strain (positive control).

Design of experiments

The experimental design was completely randomized with four replicates for the four experiments. The experiments are described as follows: (1) Two treatments, one with the inoculation of *Trichoderma asperellum* UFT 201 and one control without inoculation (absolute control); (2) Three treatments, one with inoculation of *Trichoderma asperellum* UFT 201, one treatment with inoculation of the standard *Trichoderma harzianum* strain CIB T23 (positive control) and one treatment without inoculation (absolute control); (3) and (4) Three treatments, one with inoculation of *Trichoderma asperellum* UFT 201, one with commercial inoculant as positive control and one treatment without inoculation (absolute control). The liquid commercial inoculant was composed by *T. harzianum*, *T. asperellum* and *T. koningiopsis* (concentration of 1 × 10^{11} CFU mL^{-1} and recommend dose of 300 mL ha^{-1}).

Treatment of soybean seeds and inoculation

The soybean cultivar M 8644 ipro was used in the first experiment. The soybean cultivar M 8349 ipro was used in the second experiment. The soybean cultivar M 9056 RR was used in the third and fourth experiments. Soybean seeds were initially inoculated with rhizobium *(Bradyrhizobium japonicum*) in all experiments. SEMIA 5079 and SEMIA 5080 strains for soybean (3 × 10^9 CFU mL^{-1}) were used. The seeds were sown at a ratio of 10 seeds per pot. The thinning was done between five and seven days after germination and two plants per pot were maintained. The plants were irrigated daily as needed for field capacity maintenance.

Biomass evaluations

The plants were harvested by separating the root system from the aerial part of the plants and the roots were washed in running water to remove the adhered soil. The nodules were removed from the roots and counted. Then, the material was placed for oven drying with forced aeration at 75°C until constant weight.

In the first experiment, two evaluations were made at two separate times, the first at 10 days after plant emergence (DAPE) and the second at 20 DAPE. In the second and third experiment,

Table 3. Concentration of solubilized phosphate (μg mL^{-1}) in NBRIP medium (modified) and production of IAA (μg mL^{-1}) in potato dextrose broth (PD) with L-tryptophan by *Trichoderma asperellum* UFT 201 and *T. harzianum* CIB T23 (positive control).

Isolates	P	pH	% PS	IAA	% IAA
T. asperellum UFT 201	9.9^a	5.5	167.8	1.9^a	126.7
T. harzianum CIB T23	5.9^b	5.1	100	1.5^a	100
Absolute control (not inoculated)	0.5^c	6.4	-	0.2^b	-
CV(%)	10.8	-		9.8	-

Means followed by the same lowercase letter in the column do not differ by Duncan's test at 5% significance. %PS = percentage of phosphate solubilization in relation to positive control after 7 days of growth; %IAA = percentage of indole acetic acid production in relation to positive control after 7 days of growth; CV = Coefficient of variation.

the evaluations were carried out at 40 days after planting (DAP). The shoot dry mass (SDM), the root dry mass (RDM), the total dry mass (TDM) and the relative efficiency (RE) for the SDM, RDM and TDM were determined. The RE was calculated according to the equation:

RE = (Dry mass inoculated by *Trichoderma*/Dry mass without inoculation) × 100.

In the fourth experiment, the evaluations were also carried out at 40 days after planting (DAP). The SDM, RDM, TDM, number of nodules (NN), nodules dry mass (NDM) and RE were determined. In addition, the SDM was ground in a knife mill and a sample was taken to evaluate the nutritional status of the plants. The nitrogen (N) contents were determined by the Kjeldahl method. The nitrogen accumulation in shoots (NAS) was calculated by multiplying the mass by the N content.

Statistical analysis

The data were submitted for analysis of variance and test F. The means of the treatments were grouped by the Duncan test at 5% of probability. The statistical software used was Assistant.

RESULTS AND DISCUSSION

In the laboratory experiments to determine the capacity of phosphate solubilization and synthesis of indole acetic acid (AIA), the treatment with *T. asperellum* UFT 201 had a phosphorus concentration and a percentage of phosphate solubilization of 67.8% significantly higher ($p < 0.05$) than the positive control treatment (*T. harzianum* CIB T23) (Table 3). There was a reduction of pH in the culture media with *T. asperellum* UFT 201 and the positive control in the liquid medium with calcium phosphate. In addition, the *Trichoderma* isolates used were able to produce indole acetic acid (IAA) in potato dextrose broth supplemented with L-tryptophan, but without significant difference with the positive control. However, treatment with *T. asperellum* UFT 201 showed an increase in IAA production of 26.7% higher than the positive control *T. harzianum* CIB T23 (Table 3).

The increase observed in SDM, RDM and TDM variables for the treatment inoculated by *T. asperellum* UFT 201 in relation to the positive control and absolute control treatments for the soybean plants was probably due to the ability of phosphate solubilization and indole acetic acid synthesis observed for experiment 1 in a greenhouse (Table 3). These results agree with those observed in other agricultural cultures inoculated by specific strains of *Trichoderma*. According to Hoyos-Carvajal et al. (2009), the increase in biomass production due to inoculation with *Trichoderma* spp. may be related to the production of growth hormones or analogs. Several species of fungi have been reported to produce auxins, which are fundamental hormones produced by fungi in symbiotic interactions with plants that affect growth and development (Chagas et al., 2015; Contreras-Cornejo et al., 2016).

The inoculant *T. asperellum* UFT 201 presented IAA production and promoted an increase in the biomass production of soybean plants, indicating a relation between the production of hormones and biomass. The accumulation of biomass in soybean plants may be related to the production of hormones or growth factors, greater efficiency in the use of some nutrients such as phosphorus and the increase of the availability and absorption of this nutrient by plants. Thus, the fungus *T. asperellum* UFT 201 together with the synthesis or stimulation of phytohormones can acidify the environment where it is established by the secretion of organic acids such as gluconic, citric or fumaric acids (Gómez-Alarcón and Torre, 1994). According to Harman et al. (2004), these acids are the result of the metabolism of the carbon source, mainly glucose, and they can solubilize phosphates, micronutrients and cations including iron, manganese and magnesium. Therefore, the addition of *Trichoderma* in soils with scarcity of these cations could result in biofertilization by the solubilization of the available metals or the addition of poorly soluble natural phosphates as an alternative of P supplies in the soil. This would result in increased biomass production and crop yields (Contreras-Cornejo et al., 2016).

In the greenhouse experiments, for the first experiment, the treatment with the inoculation of *T. asperellum* UFT 201 was superior than the absolute control (without inoculation) for shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM) at 10 and 20 DAPE (Table 4). On the other hand, increased values ($p<0.05$)

Table 4. Biomass analysis for the first experiment in soybean cultivar M 9056 RR inoculated by *Trichoderma* at 10 and 20 days after plant emergence.

Treatments	SDM (g)	RDM (g)	TDM (g)
		10 DAPE	
T. asperellum UFT 201	1.05[a]	0.75[a]	1.80[a]
Absolute control (not inoculated)	0.64[b]	0.30[b]	0.94[b]
CV (%)[4]	19.2	23.4	17.8
	*	*	**
		20 DAPE	
T. asperellum UFT 201	2.77[a]	1.69[a]	3.66[a]
Absolute control (not inoculated)	1.45[b]	1.13[b]	1.81[b]
CV (%)	18.3	17.9	13.9
	*	*	**

Means followed by the same lowercase letter in the column do not differ by Duncan's test at 5% significance. SDM = Shoot dry mass; RDM = Root dry mass; TDM = Total dry mass; DAPE = Days after plant emergence; CV =Coefficient of variation. * Significant at 1%. ** Significant at 5%.

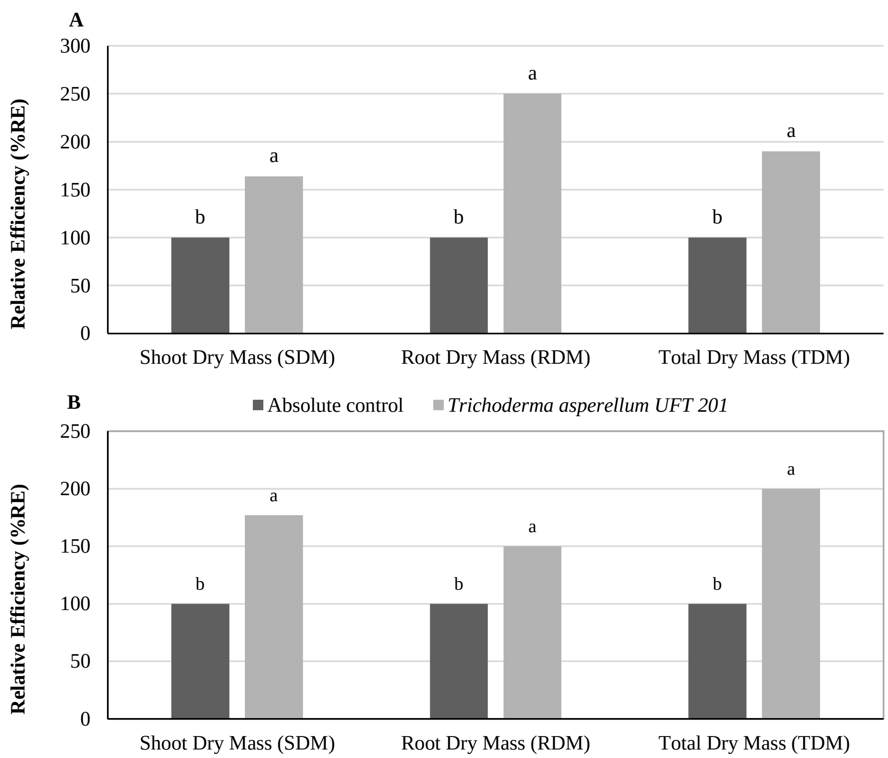

Figure 1. Relative efficiency for shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM) of soybean cultivar M 9056 RR inoculated by *Trichoderma asperellum* UFT 201 in relation to the absolute control (without inoculation). 10 DAPE (days after plant emergence) (A); 20 DAPE (days after plant emergence) (B). Means for each biomass assessment followed by the same lower-case letter do not differ by the Duncan test at 5%.

of relative efficiency (RE) of 64% in SDM, 150% in RDM and 90% in TDM were observed for the treatment inoculated by *T. asperellum* UFT 201 at 10 DAPE (Figure 1A). Likewise, Relative efficiency (ER) values for the treatment inoculated by *T. asperellum* UFT 201 with 77% in SDM, 50% in RDM and 100% in TDM higher than the absolute control at 20 DAPE (Figure 1B).

In the second greenhouse experiment, the capacity of

Table 5. Biomass analysis for the second experiment in soybean cultivar M 8644 ipro inoculated by *Trichoderma* at 40 days after planting (DAP).

Treatments	SDM (g)	RDM (g)	TDM (g)
T. asperellum UFT 201	4.33[a]	3.92[a]	8.25[a]
Positive control (*T. harzianum* CIB T23)	3.30[b]	3.00[b]	6.30[b]
Absolute control (not inoculated)	3.41[b]	2.59[b]	6.00[b]
CV (%)	9.9	20.4	11.7

Means followed by the same lowercase letter in the column do not differ by Duncan's test at 5% significance. SDM = Shoot dry mass; RDM = Root dry mass; TDM = Total dry mass; CV = Coefficient of variation.

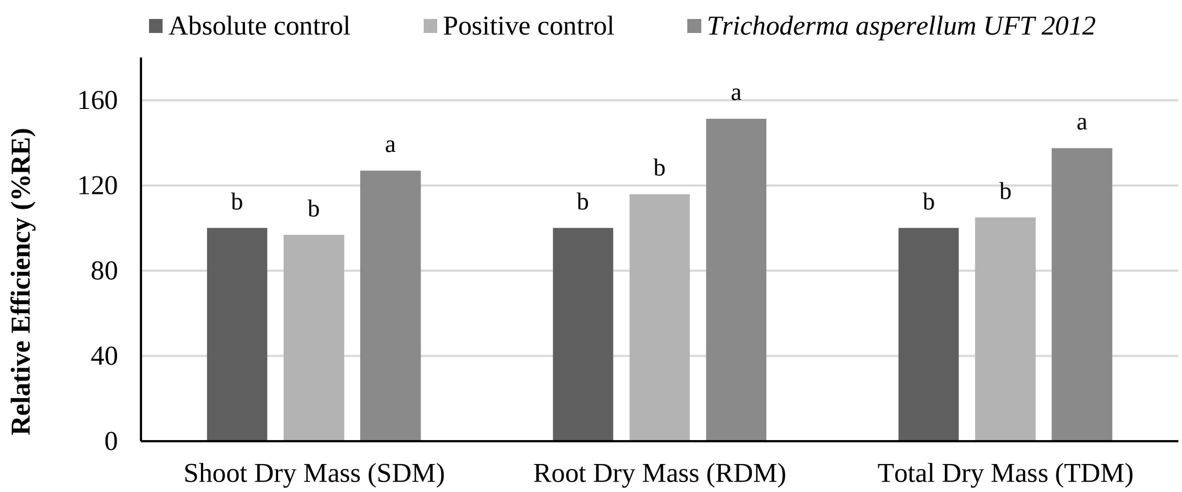

Figure 2. Relative efficiency for shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM) of soybean cultivar M 8644 ipro inoculated by *Trichoderma asperellum* UFT 201 in relation to the absolute and positive control at 40 days after planting. Means for each biomass assessment followed by the same lower-case letter do not differ by the Duncan test at 5%.

plant growth promotion by *Trichoderma asperellum* UFT 201 was evidenced by the biomass values significantly higher ($p < 0.05$) of SDM, RDM and TDM than the positive control and absolute control at 40 days after planting (DAP) (Table 5). The relative efficiency (ER) of experiment 2 showed higher values ($p < 0.05$) for treatment with *T. asperellum UFT 201* with means above 25% than the absolute control and positive control for SDM. Values above 30% and 50% relative efficiency in RDM were detected for *T. asperellum* UFT 201 compared to the positive and absolute control respectively. Finally, values above 30% relative efficiency in TDM were found for *T. asperellum* UFT 201 in relation to positive and absolute control (Figure 2).

For the third greenhouse experiment, the evaluation of the biomass of treatment inoculated by *T. asperellum* UFT 201 was significantly higher ($p < 0.05$) than the positive control and absolute control treatments for SDM, RDM and TDM (Table 6).

The relative efficiency (RE) for the biomass evaluations had superior results ($p < 0.05$) for the treatment inoculated by *T. asperellum* UFT 201 with means above 152, 73 and 102% for SDM, RDM and TDM, respectively; compared to the absolute control. With 67, 22 and 38 for SDM, RDM and TDM, respectively; compared to the positive control (commercial inoculant ICB) (Figure 3). For the fourth greenhouse experiment, the shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), nitrogen content (N content) and nitrogen accumulation in shoots (NAS) were significantly higher ($p < 0.05$) for treatment with the inoculation of *T. asperellum* UFT 201. The number of nodules (NN) and nodules dry mass (NDM) were higher ($p < 0.05$) for treatments inoculated by *T. asperellum* UFT 201 and positive control than the absolute control without inoculation (Table 7). The relative efficiency evaluations in the treatment inoculated by *T. asperellum* UFT 201 were highlighted ($p < 0.05$) in relation to the positive control and absolute control with means above 30, 20, and 27% for SDM, RDM and TDM, respectively (Figure 4).

Hence, species of *Trichoderma* spp. can promote increases of up to 300% in plant growth according to Brotman et al. (2010). The results obtained in greenhouse experiments confirmed the results of Silva et al. (2011),

Table 6. Biomass analysis for the third experiment in soybean cultivar M 8349 ipro inoculated by *Trichoderma* at 45 days after planting (DAP).

Treatments	SDM (g)	RDM (g)	TDM (g)
T. asperellum UFT 201	2.17[a]	1.49[a]	3.66[a]
Positive control (commercial inoculant ICB)	1.44[b]	1.05[b]	2.49[b]
Absolute control(not inoculated)	0.86[c]	0.86[c]	1.81[c]
CV (%)	8,3	8,9	8,4

Means followed by the same lowercase letter in the column do not differ by Duncan's test at 5% significance. SDM = Shoot dry mass; RDM = Root dry mass; TDM = Total dry mass; CV = Coefficient of variation.

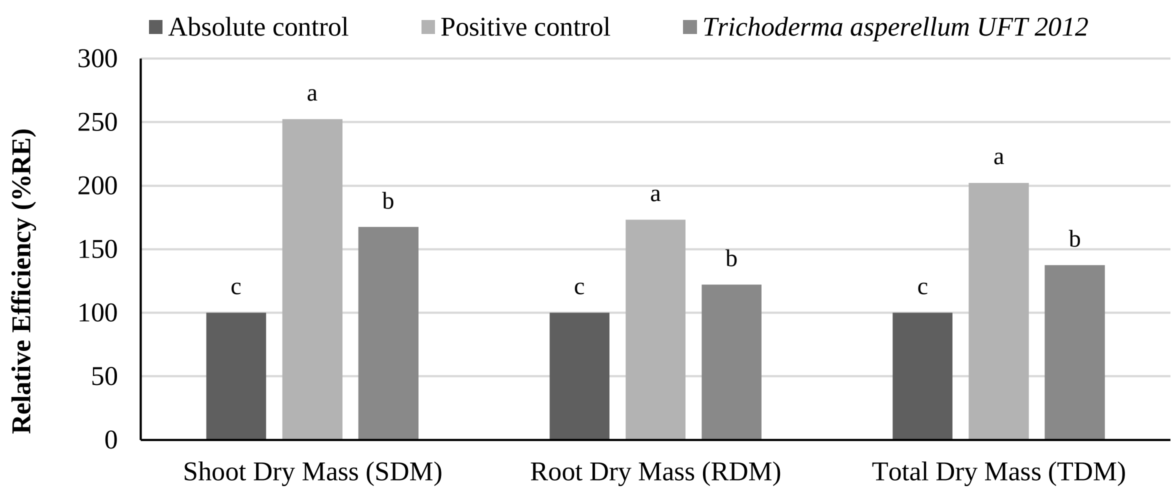

Figure 3. Relative efficiency for shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM) of soybean cultivar M 8349 ipro inoculated by *Trichoderma asperellum* UFT 201 in relation to the absolute and positive control (commercial inoculant ICB) at 40 days after planting. Means for each biomass assessment followed by the same lower-case letter do not differ by the Duncan test at 5%.

where they evaluated the effect of *Trichoderma* on cucumber growth and observed a significant increase in relation to the control without inoculation of *Trichoderma*. Researchers have been carried out with fungi of the genus *Trichoderma* spp. Some strains of *Trichoderma* spp. promote plant growth by increasing nutrient availability and production of growth hormones (Louzada et al., 2009; Chagas et al., 2015). Likewise, the present work could verify the positive results of inoculation by *T. asperellum* UFT 201.

In all the experiments there was an increase in the biomass of the root system and this increase in the root is related to the sanity of the plant provided by the microorganisms. Plants containing this microorganism associated with their roots or in the rhizosphere tend to have a better ability to survive and absorb nutrients in adverse situations. Consequently, these plants have a productive advantage over those with absence of *Trichoderma* in their roots (Contreras-Cornejo et al., 2015; 2016).

Rudresh et al. (2005) observed that inoculation with *Trichoderma* promoted an increase in the growth rate and production parameters of chickpea grown in soil with phosphorus deficiency and fertilized with insoluble rock phosphate under greenhouse and field conditions. These results in the different experiments agree with other works with different agricultural cultures inoculated with different *Trichoderma* isolates. Santos et al. (2010) concluded that the use of *Trichoderma* spp. provided positive results in the increase of fresh and dry mass of passion fruit plants from cuttings. Carvalho et al. (2011) evaluated the inoculation of *Trichoderma* isolates in the promotion of initial common bean growth. Jesus et al. (2011) emphasized the potential of *T. asperellum* as a substrate conditioner to produce coffee seedlings; they showed a positive effect on the increase of root, shoot and total biomass as well as the increase of the phosphorus absorption efficiency.

Silva et al. (2012) demonstrated that *Trichoderma* isolates from Amazonian soils increased the biomass of rice plants in greenhouse as well as potential as growth promoters. Machado et al. (2012) also emphasized that

Table 7. Biomass analysis for the fourth experiment in soybean cultivar M 9056 RR inoculated by *Trichoderma* at 40 days after planting (DAP).

Treatments	SDM (g)	RDM (g)	TDM (g)	NN	NDM (mg)	N content (g kg^{-1}/pot)	NAS (g pot^{-1})
T. asperellum UFT 201	7.53^a	4.20^a	11.73^a	26.8^a	213.3^a	12.10^a	91.1^a
Positive control	5.90^b	3.41^b	9.31^b	23.8^a	212.8^a	11.70^a	69.0^b
Absolute control	5.70^b	3.43^b	9.13^b	13.0^b	63.3^b	9.40^b	53.6^c
CV (%)	12.7	9.9	10.3	30.8	38.7	9.2	13.2

Means followed by the same lowercase letter in the column do not differ by Duncan's test at 5% significance. Positive control = commercial inoculant ICB; Absolute control = not inoculated; SDM = Shoot dry mass; RDM = Root dry mass; TDM = Total dry mass; NN = number of nodules; NDM = Nodules dry mass; N = Nitrogen; NAS = Nitrogen accumulation in shoots; CV = Coefficient of variation.

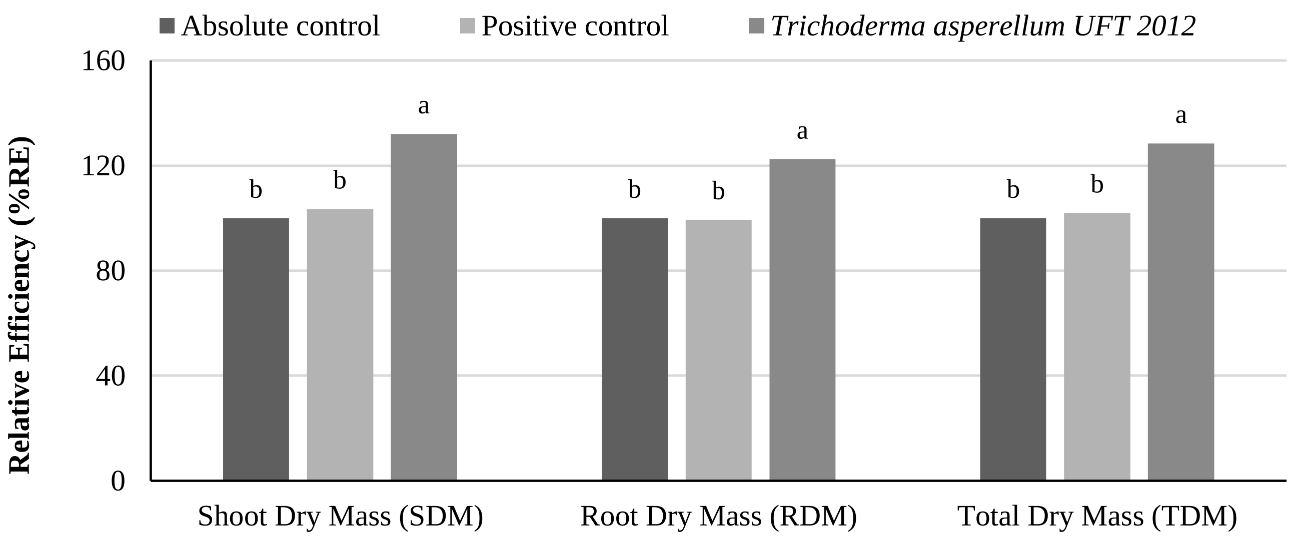

Figure 4. Relative efficiency for shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM) of soybean cultivar M 9056 RR inoculated by *Trichoderma asperellum* UFT 201 in relation to the absolute (not inoculated) and positive control (commercial inoculant ICB) at 40 days after planting. Means for each biomass assessment followed by the same lower-case letter do not differ by the Duncan test at 5%.

research has proved that *Trichoderma* spp. is efficient, practical and safe in terms of application methods, biocontrol and plant growth promotion. The results demonstrated the ability of the *T. asperellum* UFT 201 strain as an active microorganism in granulated formulation (millet) and its efficiency in promoting the initial growth of soybean plants.

Conclusion

The isolate *T. asperellum* UFT 201 solubilized calcium phosphate and synthesized indole acetic acid (IAA). This isolate had a positive effect on the increase of biomass in relation to the absolute control treatment as observed in experiment 1. In addition, the inoculation of *T. asperellum* UFT 201 presented positive results in the accumulation of biomass (Experiments 2, 3 and 4), nitrogen content and nodulation (Experiment 4). Finally, this isolate showed its potential as an inoculant plant growth promoter in soybean.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Performance of garlic cultivars under rain-fed cultivation practice at South Gondar Zone, Ethiopia

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Garlic (*Allium sativum L.*) is an important edible bulbous crop with unique culinary and medicinal purposes. It is a major cash crop widely cultivated in Libokemkem and other districts of South Gondar zone of Amhara Region in Ethiopia. However, productivity of garlic in Ethiopia in general and in South Gondar Zone in particular is very low largely due to the use of unimproved local cultivars and traditional cultural practices. Five different improved cultivars of garlic were then evaluated for yield and yield components under rain-fed production practice. This acclimatization and performance evaluation at three different locations (Angot, Ginaza and Woreta) was laid in randomized complete block design with three replications. Cultivar Adiszemene local (55.44, 39.82 and 22.28 quintal per hectare (q/ha)) produced consistently high dry bulb yield at the three locations. Cultivar Chefe was found to be the lowest yielding at Angot (16.07 q/ha) and Ginaza (22.56 q/ha), whereas cultivars Kuriftu (11.92 q/ha) and Tsedey (10.06 q/ha) were the lowest yielding at Woreta indicating profound effect of environment on yield. Overall result revealed that statistically significant (P<0.05) high dry bulb yield (39.18 q/ha) was recorded in cultivar Adizemene local, followed by cultivar Holleta (31.32 q/ha). These cultivars with consistent high performance and wide adaptability would then be demonstrated and popularized for wide spread cultivation.

Key words: Acclimatization, allicin, bulb, environment, medicine, spice.

INTRODUCTION

Garlic (*Allium sativum L.*) is an important edible bulbous crop belonging to the family Alliaceae along with onion, shallot, leek and chives. It is the second most widely cultivated Allium after onion and has been used throughout history for culinary and medicinal purposes (Pandey, 2012). Garlic has higher nutritive value than other bulbs crops (Abou El-Magd et.al, 2012). Keeping in view of its medicinal value, especially Allicin of garlic which has antibacterial properties (Al-Otayk et. al, 2009 and Sterling and Eagling, 1997), garlic is widely used in all households throughout the year. According to Amagase et al (2001) and Iciek et al (2009), the unique flavor and health-promoting functions of garlic are generally attributed to its rich content of sulfur-containing compounds, that is, alliin, g-glutamylcysteine, and their derivatives. Processing a fresh and intact garlic bulb by crushing, grinding, or cutting induces the release of the vacuolar enzyme alliinase, which very quickly catalyzes

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allin to allicin. Allicin is a very unstable compound, soon rearranged and transformed into numerous lipid-soluble sulfur-containing by products, mostly diallyl disulfide (DADS) but also diallyl sulfide (DAS), diallyl trisulfide (DATS), allylmethyl trisulfide, and diallyl tetrasulfide (Iciek et.al, 2009). These compounds emit strong odors and are kept in garlic oil. Garlic is used in sauces, soups and for seasoning foods. The cloves are also pickled in vinegar. Garlic is rich in phosphorus, calcium and carbohydrates (Khan et al., 2018).

Garlic is grown worldwide in all temperate to subtropical and tropical hilly areas as an important spice and medicinal plant (Pandey, 2012). Clinically, garlic has been evaluated for lowering blood pressure, cholesterol, and glucose concentration, as well as for the prevention of arteriosclerosis and cancer (Tsai et al., 2012). It was further indicated that, epidemiologically, garlic consumption inversely correlates with the risk of oral, stomach, esophageal, colon, and prostate cancers. In addition, the biological activities of garlic, including antibacterial, antithrombotic, antioxidant, immuno-modulatory, and antidiabetic actions and modulation of drug metabolism, have been extensively investigated. Despite its various uses for flavouring food and treatment of health problems, garlic breeding has been hampered for the plants rarely produce seed and are propagated asexually by cloves or sometimes by top sets. Cultivar development for better yield and quality was therefore solely based on clone selection from variations due to mutation. According to Etoh and Simon (2002), only limited genetic variation can be introduced via mutations and it is very hard to make significant progress by mutation breeding alone. However, Khar et al (2011) and Senula and Keller (2000) reported that garlic exhibits a wide range of diversity in morphological, reproductive and bulb traits because of its apomictic nature which leads to the existence of extensive somatic mutations (Ata, 2005). It was further indicated by Jabbes et al. (2012) that garlic presents, in spite of its vegetative multiplication, a great diversity from agro-morphological and biochemical point of view (Abdoli et al., 2009; Burba and Gomez Riera, 1997; Hong, 1999; Lallemand et al., 1997; Messiaen et al., 1993; Ovesna et al., 2007 and Stavelìkova, 2008.). This variability is required; in fact, researchers benefit from the wide diversity of garlic for the selection of best genotypes. The genetic diversity serves as a source of genotypes adapted to local conditions (Baghalian et al., 2005).

Ethiopia with diversified agro-ecological conditions is suitable for garlic production. South Gondar zone in Amhara region of Ethiopia is potentially endowed with favorable climatic and soil conditions for the cultivation of garlic both under rain fed and using irrigation. Garlic in this zone particularly in Libokemkem District is a major cash crop produced both under rain fed and irrigation in larger plots similar to field crops such as maize, rice and 'tef' (*Eragrostis tef*). Rain fed garlic in Libokemkem is usually planted from June to July and harvested in October and the plot is sown immediately with chick pea, whereas irrigated garlic is planted in November after harvesting, cereals such as 'tef' and maize produced in the rainy season from May to October.

The contribution of this sector towards ensuring engagement of large number of labor with the participation of female and youths could not be undermined since garlic production is a labor intensive job. Despite multifaceted uses, garlic suffers from several problems that caused low productivity and poor quality largely attributable to the use of unimproved local cultivars with poor productivity. Yeshiwas et al (2017) also indicated that lack of improved varieties and garlic rust is the major one among many contributing factors responsible for low production and productivity of garlic in Ethiopia. Moreover, due to repeated cultivation of similar cultivars for several years in specific plots, fungal contamination of planting materials and soil is observed in the vicinity of Libokemkem areas. Besides applying improved husbandry practices, it is therefore crucial to identify appropriate cultivar with high productivity and quality suitable to target environments. With an ultimate objective of supplying healthy planting materials of alternative cultivars, this trial was therefore undertaken to evaluate cultivars for acclimatization and performance studies at Fogera and Libokmekm districts in Northwestern Ethiopia.

MATERIALS AND METHODS

The experiment was conducted at three locations: two in Libokemkem District (Angot and Ginaza kebeles) and one in Fogera District (Woreta kebele) of south Gondar zone of Amhara Region in Ethiopia. Planting materials of released garlic cultivars, Viz., Chefe, Holleta, kuriftu and Tsedey were obtained from Debre Zeit Agricultural Research Centre while bulbs of Adiszemene local were bought from Adiszemene market. Cultivars were then laid in randomized complete block design with three replications in three locations namely, Woreta, Angot and Ginaza in South Gondar Region of northwestern Ethiopia.

Land was prepared to a fine tilth through repeated plowing the experimental plot. Ridges of 20 centimeter (cm) width and 25 cm height along with 40 cm furrow width were prepared. Cloves (bulb splits) were then planted at both sides of the ridge with 10 cm distance between plants.

The spacing used was therefore 40 cm furrow width, 20 cm distance between rows on the ridge and 10 cm between pants. Effective plot size was 4.8 m^2 (2.4m x 2m) and contained 160 plants on two meter long four ridges (8 rows).

Planting dates were June 19, 26 and 30, 2018 for garlic trials at Woreta, Angot and Ginaza, respectively. Depending on maturity time of cultivars, harvesting at these locations was accomplished from September 20 to October 15, 2018.

A mix of Nitrate Phosphate sulfur (NPS) (38:19:5) at the rate of 242 kg/ha and Urea (46%N) fertilizers at the rate of 100 kg/ha were applied. NPS fertilizer was applied once at planting while Urea was applied in two splits, the first at full emergence (10-15 days after planting) and the second at one and 1/2 months after planting. Hand weeding and cultivation (hoeing) was performed throughout the field evaluation period. Stand count, plant height and record for

Table 1. Mean dry yield, days to maturity and plant height of garlic cultivars at Angot Kebele in 2018 rainy season (June to September).

Cultivar	Yield (q/ha)	Yield per plant (g)	Days to maturity	Height (cm)
Adiszemene local	55.44	19.27	100.00	56.17
Holleta	42.74	18.52	103.67	57.43
Tsedey	40.88	16.63	110.00	56.83
Kuriftu	30.62	11.50	104.67	51.93
Chefe	16.07	6.32	95.00	50.80
LSD (0.05)	11.39	3.39	3.72	8.04
CV%	16.29	12.45	1.92	7.82

Table 2. Mean dry yield, days to maturity and plant height of garlic cultivars at Ginaza Kebele in 2018 rainy season (June to September).

Cultivar	Yield (q/ha)	Yield per plant (g)	Days to maturity	Height (cm)
Adiszemene local	39.82	17.18	98.00	41.60
Holleta	30.51	13.25	99.67	48.55
Tsedey	25.24	14.51	106.00	50.27
Kuriftu	24.71	12.81	106.00	51.38
Chefe	22.56	9.43	96.00	42.65
LSD(0.05)	7.17	2.07	2.57	3.35
CV%	13.37	8.18	1.35	3.79

disease incidence were made during the vegetative phase. Data were recorded on maturity date, bulb size, dry yield per plant and plot. Data were subjected to analysis of variance and least significance difference (LSD) was used to compare treatment means when there was statistically significant difference (P<0.05)

RESULTS AND DISCUSSION

Significant differences (P<0.05) among cultivars were recorded for dry bulb yield in quintals per hectare, yield per plant and days to maturity. Cultivars Adizemene local (55.44 q/ha) followed by Holleta (42.74 q/ha) and Tsedey (40.88 q/ha) gave the highest dry bulb yield in quintal per hectare at Angot kebele of Libokmkem District while Chefe (16.07 q/ha) was the lowest yielding cultivar. Similarly, field trials conducted by Omnarayan and Thakre (2018) to study the performance of different varieties on growth, yield and quality of Garlic (*Allium sativum* L.) under agro-climatic conditions of Allahabad revealed that best results were recorded on all the parameters in variety KS-2 followed by variety G-4 and the minimum was recorded with Agrifound White. Significant variation among the genotypes for total yield and marketable yield was also reported by Aslam et al. (2016).

Cultivar Chefe was early in maturity taking only 95 days at Angot. Besides, Holleta (57.43 cm) was found to be the tallest cultivar at Angot, though differences in height among cultivars were not statistically significant (Table 1). As compared with other cultivars, Adizemene local and Holleta gave the highest yield in quintal per hectare at Ginaza kebele (Table 2). Ayalew et al. (2015) also obtained significantly highest yield from the local variety at Dabat District of Northwestern Ethiopia further reflecting that varieties released for certain areas may not suit other areas. However, the lowest yielding cultivars were Tsedey (10.06 q/ha) and Kuriftu (11.92 q/ha) at Woreta, and Chefe (22.56 q/ha) at Ginaza kebeles. As compared to other cultivars, Adiszemene local and Chefe (94 days) were early maturing at Woreta. Furthermore, Adiszemene local (43.63 cm) was shorter in height than other cultivars at Woreta, whereas Chefe (42.65 cm) and Adiszemene local (41.60 cm) were the shortest cultivars at Ginza (Tables 2 and 3). On the other hand, trials conducted during dry periods under irrigation at Dabat District, Northwestern Ethiopia indicated that BishoftuNech was early maturing variety (135 days) followed by Kuriftu (143 days), whereas MM-98 matured late at 176 days after planting (Ayalew et al., 2015). This could be attributable to differences in growing conditions including agro-ecology (temperature, altitude etc), soil and cultural practices. Furthermore, Khatun et al (2014) showed significant difference among varieties in plant height, weight of bulb per plant and number of bulb per square meter which might have increased yield significantly. It was also indicated that the highest yield (8.11and 8.04 ton per hectare during two successive years) was obtained from BARI Roshun 2 while the

Table 3. Mean dry yield, days to maturity and plant height of garlic cultivars at Woreta Kebele in 2018 rainy season (June to September).

Cultivar	Yield (q/ha)	Yield per plant (g)	Days to maturity	Height (cm)
Adiszemene local	22.28	8.72	94.00	43.63
Holleta	20.72	9.20	110.00	51.26
Tsedey	10.06	6.31	112.00	46.18
Kuriftu	11.92	7.96	114.33	47.53
Chefe	21.11	8.36	94.00	47.05
LSD(0.05)	8.3	2.8	3.87	3.95
CV%	25.59	18.32	1.96	4.45

Table 4. Mean dry yield, days to maturity and plant height of garlic cultivars in the three locations in 2018 rainy season (June to September).

Cultivar	Yield (q/ha)	Yield per plant (g)	Days to maturity	Height (cm)
Adiszemene local	39.18	15.06	97.33	47.13
Holleta	31.32	13.65	104.44	52.41
Tsedey	25.39	12.48	109.33	51.09
Kuriftu	22.42	10.76	108.33	50.28
Chefe	19.81	8.04	95.00	46.83
LSD (0.05)	4.56	1.57	1.72	2.88
CV%	17.11	13.56	1.73	6.03
Location	**Yield (q/ha)**	**Yield per plant (g)**	**Days to maturity**	**Height (cm)**
Angot	37.15	14.45	102.67	54.63
Ginaza	28.51	13.43	101.13	46.89
Woreta	17.22	8.11	104.87	47.13
LSD(0.05)	3.54	1.22	1.33	2.23

lowest yield (6.38 and 5.50 ton per hectare during two successive years) was obtained from local variety. It was also reported in Onvegetables (2018) that out of nine garlic cultivars evaluated in Mount forest, Ontario, Thermadore performed the best but not significantly better than Messadore or Saba Gold. Knowing more about cultivar performance will allow one to make more viable decisions in the future when it comes to trying different cultivars for large scale commercial production.

Overall highest yield was obtained from Angot followed by Ginaza (Table 4) that could mainly be attributable to suitability of soil and environmental condition for the manifestation of genetic potential of different cultivars. The effect of different environmental factors on performance of garlic cultivars was also emphasized by Khan et al. (2018). Raslan et al. (2015) also indicated that garlic yield and quality vary greatly with cultivar, location, soil type, agricultural methods and harvest date. According to Ennes (1990) varieties do not perform equally in all environments, but some tend to be close to the ideal than others. Likewise, Foreaker (2015) reported that different types of garlic were chosen for two separate growing seasons at Alaska. Indeed, cultivars response is therefore measured through interaction of genotypes and the environments.

Overall mean dry bulb yield from the three locations was significantly high in cultivar Adiszemene local followed by Holleta. Cultivars Chefe and Adiszemene local were early maturing and the shortest in height (Table 4). Height in centimeter was strongly correlated with yield at Angot (r=0.84) (Figures 1, 2 and 3). This is inconformity with the reports of Zakari et.al (2017) that the increase in plant heights, number of leaves and other positively correlated characters increased the amount of assimilates being produced and translocated to the sink which finally has effect on the yield. Insignificant correlation (-0.48 and 0.02) was also observed between height and yield at Ginaza and Woreta. According to Albuquerque et.al (2017), correlations among several quantitative parameters evaluated were verified using phenotypical correlation coefficients because most of them were significant (r>0.7). Bulb production is correlated with the vegetative growth (Adekpe et al., 2007). Garlic plants with well-developed vegetative

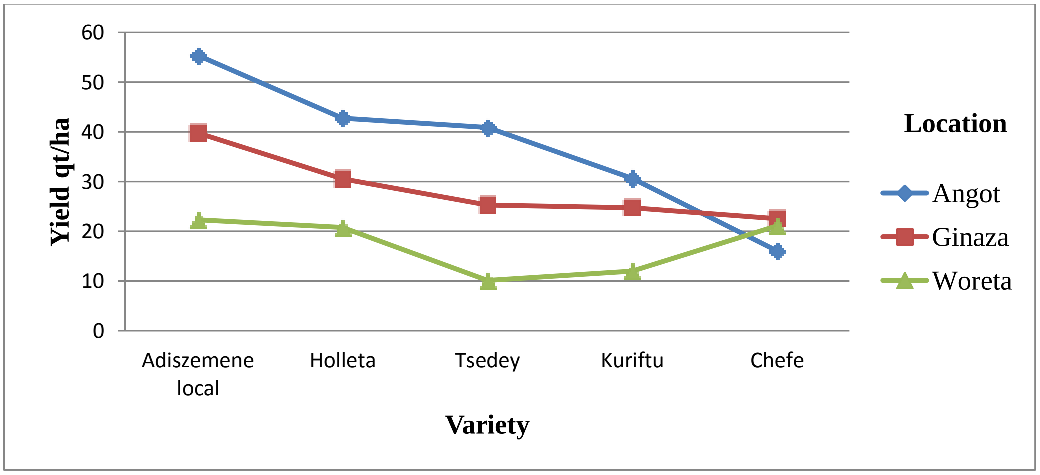

Figure 1. Yield in quintal per hectare of garlic cultivars at different locations, Ethiopia.

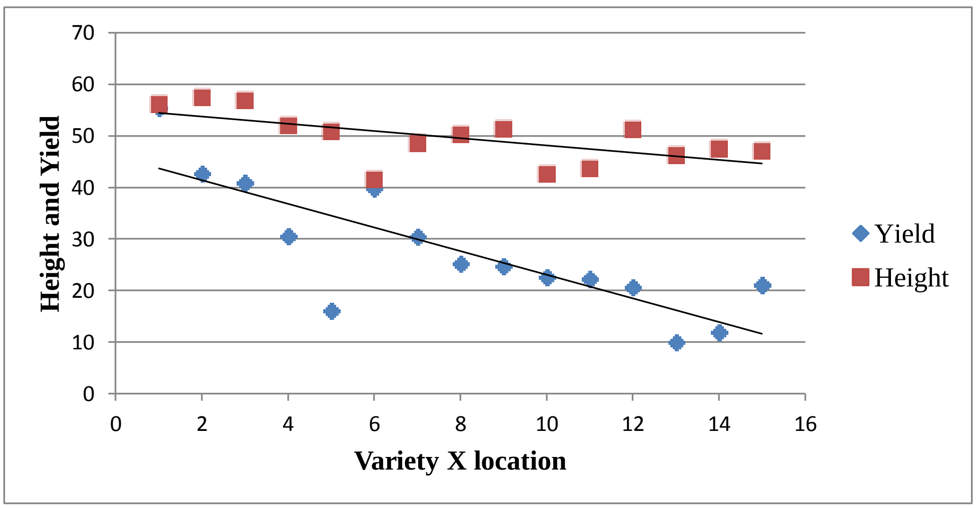

Figure 2. Correlation between height in cm and Garlic yield in qt/ha (r=0.52).

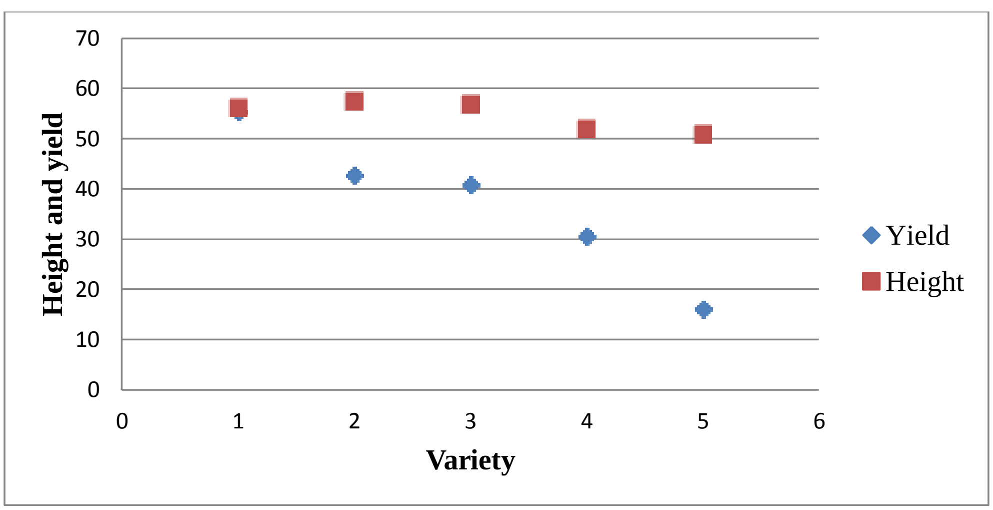

Figure 3. Correlation between height in cm and yield of Garlic in qt/ha at Angot, Ethiopia (r=0.84)

structures have effective source-drain systems for nutrient and photoassimilate translocation to the bulbs from the leaves and the pseudo-stems. This property results in a greater potential for the production of large bulbs (Mathew et al., 2011).

Conclusion and recommendations

Cultivars Chefe and Adiszemene local were early maturing, while Holleta was intermediate and Tsedey and Kuriftu were late maturing. On the other hand, Chefe was the lowest yielding and Adiszemene local was the highest yielding cultivar. Yield performance of cultivars at Kebele Angot was significantly higher as compared to the other two kebeles (locations) revealing variations in suitability of soil and environmental conditions for the cultivation of garlic. Plant height was strongly correlated with dry bulb yield at Angot which is the most appropriate location for garlic cultivation suggesting that plant height could be used as selection criterium in cultivar development of garlic. Overall performance revealed that cultivars Adiszemene local and Holleta were found to be the best yielding cultivars suitable for cultivation across locations. These cultivars can therefore be recommended for on farm demonstration to further verify performance of these cultivars with active participation of farmers, extension experts and development agents. Popularization of the cultivars and multiplication of healthy planting material for wide spread dissemination will therefore rely on feedback from demonstration and divulgation efforts.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Women involvement in the fishery activities of two coastal communities in Sierra Leone

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Women make up an important part of the fishing sector and play critical roles, particularly, in small-scale fisheries and increasingly in capture fishing and other activities. However, the roles of women are often undervalued due to the lack of attention to gender roles in fisheries, especially in Africa. This research was therefore motivated to investigate the roles of women in two coastal communities of Sierra Leone. Structured questionnaires were administered to 200 randomly selected women involved in fisheries activities in Goderich and Tombo (the two largest fish landing communities in Sierra Leone). Results obtained showed that married women between ages between 20 – 50 years were more actively involved in fisheries activities in Goderich and Tombo. Findings of the study showed that 100% of the women were involved in the processing and marketing of fish and fish related products. Most of the respondents affirmed that the fisheries have increased their income, while others said that it reduced their expenditure on food supply and other household needs. Profits made according to 60% of the respondents ranged from Le 400,000 to Le 500,000 ($52.3 – $65.4), while 40% make close to Le 600,000 ($78.4) on monthly basis. Woods for fish smoking in Goderich and Tombo were mangrove (93.6%) and forest woods (6.40%.). Constraints identified by the respondents in the two communities were poor state of the landing sites and poor fish handling, inadequate cold room and smoking kilns, poor access to credit, high labour and processing inputs cost, high illiteracy and poor toilet facilities. The low level of respondents` education prevents women from taking part in decision-making that affects their livelihood in the communities.

Key words: Coastal communities, Goderich, Tombo, women, fishery activities, livelihood, constraints and Sierra Leone.

INTRODUCTION

Agriculture, which embraces quantum of practices that provides livelihood and sustenance to many globally, has been recognized as engine of growth and poverty reduction in countries where it is the main occupation of the poor (World Bank, 2008). African women according to Odili et al. (2012) have the highest female participation rate in agriculture of all regions in the world. It is also important to note according to FAO (2011) that women comprise about 43% of the global agricultural labor force, especially in developing countries. Their contribution to

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agricultural output is undoubtedly extremely significant, as women produce 60- 80% of food in agriculture. This important role however is difficult to quantify with some level of accuracy (FAO, 2011). According to Ekong (2003), women play a pivotal role in the food security because of their strategic position in the household and productive work they do outside the home. Alamu and Mdahili (1994), Alamu (1992) and Ijiff (1990) reported that these dynamic women work long hours daily in household chores, fishing, fish processing, packaging, preservation, storage, marketing of fish and other income generating non-fisheries activities. Odili et al. (2012) reported that women are more commonly occupied in subsistence and commercial fishing from small boats and canoes in coastal or inland waters; but are rarely involved in commercial offshore and long distance fisheries. Although their contributions remain largely invisible and undocumented, they are important workforce in the fishery sectors globally.

The fisheries sector is a source of fish food and livelihood for significant proportion of people living in the coastal communities (Akinrotimi et al., 2007). Fish is the cheapest form of animal protein in the diet of the majority of coastal dwellers in Sierra Leone. Thus, the sector provides the nutritional needs as well as employment opportunities of the people because an entire family unit comprising men, women and children find employment in the sector. According to Akinrotimi et al. (2007), the sector supplies animal protein necessary for growth and income for many households in these rural communities. The roles of women in the sector are diverse; and according to Olufayo (2012), they take part specifically in fishing, processing and marketing. Women are integral part of fishing business all over the world and by tradition the managers of small-scale farms including fishponds and are responsible primarily for the post-harvest activities like processing and marketing of fish (FAO, 1996). Besides the role of being homemakers, women are becoming more involved in diverse fishing activities ranging from processor/trader to boat owner. Traditionally, the physical harvest of fish is a man's job but as women are now getting more involved, some women occasionally resort to pre-harvest activities of net mending and repairs. In the post-harvest sector, their predominant role is in purchasing, processing and marketing. Women according to Odili et al. (2012) spend prolong hours daily in fishing related activities for which they receive very little or no assistance from NGOs or other organizations. They are directly and vigorously involved with their capital in the coordination of the fisheries chain, from production to sale of fish. Their role is however not limited to fish processing and marketing but include participation in actual production in most types of aquaculture brackish-water or freshwater fishpond. They participate in various stages of fish farm development (planning, construction and actual operation) and in fish feed formulation.

In Sierra Leone, economic activities undertaken by women contribute immensely to the upkeep of many families and households. This contribution becomes more important considering the low level of salaries of many people in the country. According to the frame survey of the artisanal fisheries of Sierra Leone (IMBO/MFMR, 2003), about 85% of fish processors and traders are women with influence extending beyond the traditional spaces of food processing and marketing. Christensen (1997) reported that fish traders assist fishers with loans to buy canoes and other equipment. Notwithstanding the role and huge contributions of women, they have continued to be marginalized all over the world, more importantly in development issues (Chando, 2002), a situation that has led to underperformance of the agricultural sector in many developing countries. This study therefore was carried out assess and document information on the diverse roles and activities women in the artisanal fishing sectors of Sierra Leone and to identify the constraints faced by them in the fish supply chains of the two coastal communities of Tombo and Goderich.

METHODOLOGY

Study area

The study was carried out in Tombo and Goderich, two artisanal fishing communities in the Western district of Sierra Leone. The climate of Tombo and Goderich are mainly tropical and has distinct dry and wet season. The temperate of the area range between 21 to 23°C for the greater part of the dry season (Gwenne-Jones et al., 1978). A combination of field survey using two hundred structured questionnaires following the method described by FAO (1999), oral interview, personal observation and photographs were used to source for information on fish related activities at the study locations and women were the target groups. The questionnaires were administered to retrieve demographic, socio-economic information and information relating to constraints encountered by women. The medium of communication was *Krio* (adapted pidgin English) interpreted to English by the researchers. Data obtained from completed questionnaires were collated and analysed using Microsoft Excel programs to obtain frequency and percentages. Charts and tables were developed and used to explain the various variables of interest.

RESULTS AND DISCUSSION

Demographic information of respondents

The socio-economic characteristics of the respondents at the two landing sites are shown in Table 1. The age of the women who were actively involved in fisheries activities in Goderich and Tombo fell within the age bracket of 20 to 40 years (64%). This age group agreed with what was reported by Obande et al. (2004) on the role of women in artisanal fisheries along the lower Benue River. The result of this study is also in agreement with the work of Olowosegun et al. (2004) who explained

Table 1. Socio-economic characteristics of respondents.

Variable	Goderich (%)	Tombo (%)
Age		
20-30	31	25
31-40	37	39
41-50	20	15
50 and above	12	21
Marital Status of Respondent		
Single	24	12
Married	46	82
Divorced	17	3
Separated	3	2
Widowed	10	1
Number of children		
1	10	28
2-5	59	61
Above 5	26	4
None	5	7
Highest educational qualification		
No Education	36	48
Primary	58	35
Secondary	5	17
Vocational	0	0
Islamic	1	0
Tertiary	0	0
Experience (Years Spent Selling Fish)		
Less than 1 year	3	2
1-3 years	35	13
3-5 years	20	10
5 and above	42	75

that women in this age bracket are active, agile and full of vigour. FAO (2016) reported age range of 16 to over 50 years for women smoking fish. The age gap of the two communities is an indication that a high proportion of the age group fell within the working class of able-bodied women, who are married, a fact that supports the notion that women have to work hard to support their husbands and or totally cater to the welfare of their families. We observed that involvement of women in fisheries activities at the two study locations waned as they advanced in age. Women with age above 50 years were not actively involved in fisheries activities at the two locations and this accounted for 21% of the sampled population (Table 1). Akinrotimi et al. (2011a) observed the same trend among women in some fishing communities in Niger Delta, Nigeria. Fisheries activities is certainly not for older folks due mainly to the fact that it is energy sapping. Older folks had the responsibility of helping the younger women with domestic chores such as taking care of children. There were many married women than singles, divorced, widowed and separated respectively in the study areas. This situation probably accounted for the age group who were involved in fisheries activities. In terms of the literacy level in the two communities, the study results showed that 63% and 52% of the respondents in Goderich and Tombo respectively had some form of formal education (primary and secondary education). Ability of rural and coastal women to manage their business and home effectively has been premised on the attainment of certain level of education. The number of women with education in Goderich and Tombo were more than what Olowosegun et al. (2004) reported for women in Kainji lake basin, Nigeria. The results of this study is however at variance with Williams (2006) who affirmed that women in fishing communities are usually not well read.

Table 2. How use fishers' income they earned.

Variable	Goderich (%)	Tombo (%)
Bread winner of family		
Yes	69	76
No	31	24
Number of children sponsored in school		
1-5	61	78
6-10	6	6
11-15	2	2
None	31	14
Monthly Expenditure – Family spending		
Le 100-200,000	31	65
Le 300-400,000	42	27
Le 500 and above	27	8
If respondents live in rented apartment (Rented Apartment)		
Yes	68	73
No	32	27
How much the Respondent pay for rented monthly(Money pay on rented apartment)		
Le 10-20,000	73.52	82.19
Le 21-30,000	14.71	12.33
Le31-40,000	11.76	5.48

Respondents use of income earned

The various uses of income generated by respondents from their fisheries business is presented in Table 2. Result obtained from the study indicated that 69% of the respondents at Goderich were breadwinners of the family while at Tombo it was 76%. Respondents also affirmed to use part of the money they earn for education of their children. This study discovered that money spent on family monthly amounted to between Le 100,000 - 200,000 (Le 7,650 equal $1.00) that is 31 and 65% for Goderich and Tombo, respectively. At Goderich 27% of the respondents spent above Le 500,000 while the rate was 8% for Tombo. Younger women were observed to be more involved in the business of processing and marketing than older women and this is in agreement with the work of Wokoma (1991), Shalesha and Stanley (2000), Ekundayo and Kolo (2011) and Ajayi et al. (1989). Further, this result is also in agreement with that of Odulate et al. (2011) who reported that women in the coastal wetland areas of Ogun state Nigeria participate more in fish marketing than other fishery activities. According to FAO (2016), women are believed to be mostly responsible for skilled and time-consuming onshore tasks, such as making and mending nets, processing and marketing catches, and providing services to the boasts. This is however not the case in Sierra Leone where women are rarely found in net making and mending – these are purely male dominated engagement (Figure 1).

It is obvious that women need daily income to take care of their family in Sierra Leone, for instance where most women are head of the family, daily income is the option. Cliffe and Akinrotimi (2015) in their study noted that fisher women engage in coastal fisheries activities to meet their daily need which includes feeding, taking care of their children and lending a helping hand to support their husbands. Cliffe et al. (2011) based on their work in some rural communities of Niger Delta in Nigeria pointed out that women longing to meet daily needs were responsible for their involvement in fisheries.

Sources of respondents business capital

Funding is crucial in any fishery activity; information on sources of finance for respondents` fishery activities is presented in Table 3. As shown in the table, fish mammies and mongers have various sources of funding which include loans from cooperative society, personal savings and borrowed money from moneylenders. At Tombo, the co-operative society often help their members to purchase fish on condition that they will sell and refund the money with small interest. However, as can be seen

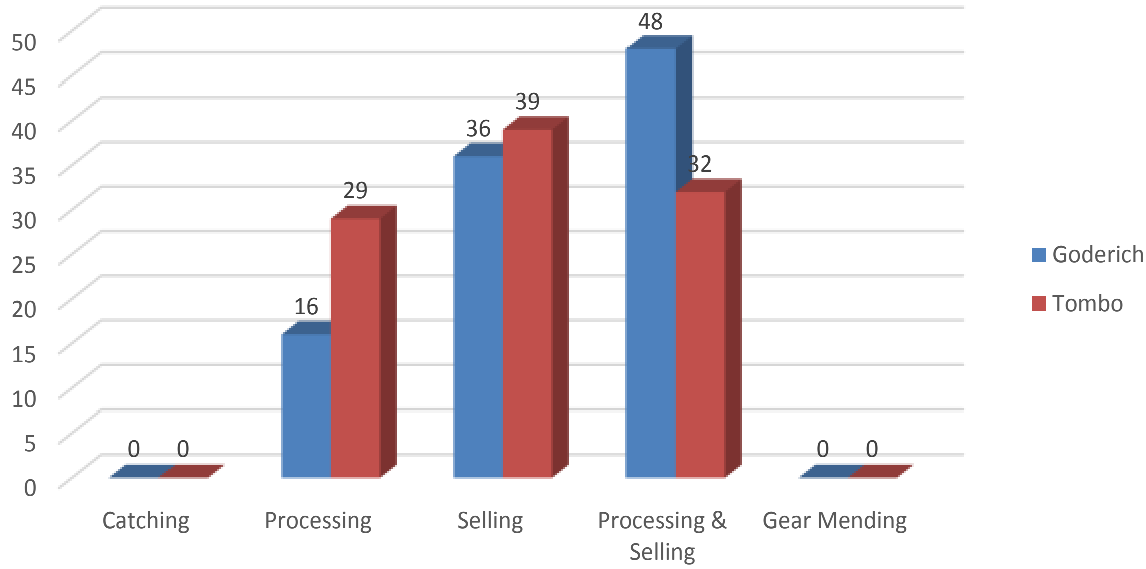

Figure 1. Fisheries activities of respondents.

Table 3. Sources of respondents finance.

Variable	Goderich (%)	Tombo (%)
The initial capital involved in fisheries activity (Sources of capital)		
Own funds	65	64
Borrowed	35	36
Others	0	0
Borrow Money from customers		
Yes	9	18
No	91	82
If respondents offer money in advance for fish?		
Yes	14	17
No	86	83
If respondents lend money to Boat owners		
Yes	0	0
No	100	100

in Table 3, most of the respondents at the two communities said that they raised the initial capital for their business (65% at Goderich and 64% at Tombo). Some of the respondents however said they obtain loan from moneylenders (35% at Tombo and 36% at Goderich). While others agreed to down payment option by their customers, this according to them freed them from the embarrassment of not meeting deadlines and the inordinate demand of randy male fishers. Initial capital outlay, poor technology and labour intensiveness according to FAO (1988) are some of the constraints affecting women fishers. Women in the coastal communities of Goderich and Tombo muted that finance, inadequacy of processing facilities and poor condition of the landing sites are major constrains they face in the business. Cliffe and Akinrotimi (2015) who mentioned lack of finance, poor transportation network, criminal activities, lack of fishing gears and lack of cooperative society as some of the problems faced by artisanal fisher women corroborated the findings of this study. Ben-Yami (2001) agreed that access to credit and insurance is very important for small-scale fisheries development.

Table 4. Respondents assets base.

Variable	Goderich (%)	Tombo (%)
Ownership of fishing gear		
Yes	0	0
No	100	100
If respondents partner have fishing gear		
Yes	0	0
No	100	100
If respondents have any household assets		
No asset	61	82
Asset(House, Lands etc)	39	18
Names of Asset		
Cars	0	0
Houses	34	32
Bicycles	0	0
None	66	68

According to Ben-Yami (2001), lack of access may constrain fishing efforts and production of small-scale fishing communities thus hindering them from increasing their production and from reaching a higher social status. The use of poor smoking facilities and techniques, which have often led to high density of smoke emission, poses great health risk (FAO, 2016).

Respondents' assets base and involvement in cooperative society

According to the respondents, the fishing business, notwithstanding some of its setbacks is highly lucrative. Some of them affirmed that besides helping to support with the care of the home and payment of children school fees, they have been able to acquire lands and build houses from their business (Table 4).

The place of co-operative society in the development of fishery trade has received considerable attention in recent years. Co-operative society aims to save the interest of small entrepreneurs in the trade from clutches of intermediaries' exploitations and promote the trade. Ostrom (1990) noted that Cooperatives in the small-scale fisheries sector helps in maximizing long-term community benefits to deal with the threats of fisheries mis-management, livelihood insecurity and poverty – harsh realities for many of the world's small-scale fishers. In this study, none of the respondents interviewed at Goderich were involved in co-operative society but at Tombo 37% of the respondents agreed to be actively involved in co-operative society (Figure 2). Those who were involved adduced reasons for their joining the cooperative societies which include but not limited to child education, marriage, naming ceremony, business and other reasons.

More than 60% of the respondents earn profit from daily sales of fish. Normally, women that sell fresh fish do not buy in large quantities because of gross lack of means of preservation and electricity to power the few available freezers at the landing sites. Co-operative societies are expected to overcome some of these shortcomings by empowering fisherwomen and promote responsible fisheries by facilitating microfinance and access to appropriate equipment and technologies (FAO, 2012). There are documented roles of women involvement in co-operative societies and specific examples are the TRY Oyster Women's Association operating in the Greater Banjul areas of the Gambia, and the Isabela Women's Association Blue Fish in Ecuador (FAO, 2012). These societies ensure that the interests of their members, viz-a-viz access to credit and equipment are taken into account, especially by encouraging decentralized resource management (FAO, 2005).

Conclusion

The findings of this study as in other studies showed that women play highly significant role in fisheries activities and coastal household economies. It was also evident that women fisher folks in Sierra Leone who endure most of household care challenges are poor and needed a boost to perform their domestic obligations. The poverty of women fisher folks in the country is all encompassing, ranging from poor access to health, education, and

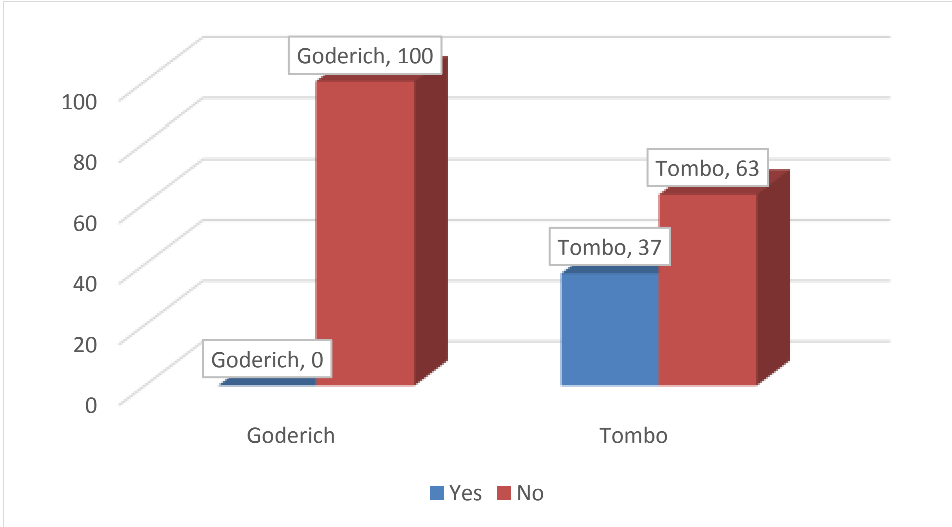

Figure 2. Respondents involvement in co-operative society.

financial capital to political marginalization. In view of the important role of these women in not only post-harvest subsector but also household nutrition and living standards, it is important to provide them with access to physical and capital resources for developing their industry and meeting their needs and aspirations. Appropriate training and semi - formal education will also help to improve the efficiency, profitability and sustainability of their activities. Skills development in value added processing techniques, establishment of cooperative society, marketing and fund raising is very important as it would help women to improve their productivity and the quality of their products. Finally, it is important to create awareness on gender issues, such that the policies and programs of government and other development agencies improve the quality of life for women in fisheries.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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