1 Introduction

Agriculture is the leading sector in the national economy and is the core driver for Ethiopia’s growth and long-term food security accounting for nearly 46% of GDP, 73% of employment, and nearly 80% of foreign export earnings (ATA 2014). Furthermore, more than 95% of the country’s agricultural output is generated by subsistence farmers who, on average, own less than one hectare of cultivated land (USDA 2010). Agricultural productivity is therefore, constrained by limited cultivation areas and high population growth.

Tigray is the most food insecure region of the country. Increasing food production to feed the fast growing population living worldwide in drought-prone areas like Tigray, Ethiopia, relies on two options, either increase the arable land to be cultivated or improve land productivity. The first option is less realistic and may not address the problem of water scarcity in view of land scarcity and limited land reserve (Tsegay et al. 2015). The use of an intercropping system is one method of increasing crop productivity and intensity of crops (Sullivan 2000).

Intercropping has several advantages such as additional income from companion crops (Samsuzzaman et al. 1999), insurance against crop failure (Beyenesh 2008), increase productivity (Sharaiha et al. 2004), stability of production, and maximization of products, soil fertility and pest control. This functional diversity contributes to ecological processes to promote the sustainability of the whole farm system (Vandermeer 1989; Altieri 1999).

The agricultural system in Tigray has been mainly cereal based. Maize (Zea mays L.) is the principal cereal crop which is grown both under rainfed and irrigation usually, for human food, but sometimes, as a cash crop. Maize is a cereal crop that is grown widely throughout the world in a range of agro-ecological environments. More maize is produced annually than any other grain. The grains are rich in vitamins A, C and E, carbohydrates, essential minerals, and contain 9% protein. They are also rich in dietary fiber and calories which are a good source of energy.
On the other hand, Potato (*Solanum tuberosum* L.) is the world’s leading vegetable crop by virtue of its inherent potential for tonnage production, remunerative income and good nutritional values. It is a starchy, tuberous crop. Potato is a promising tuber crop gradually becoming important in the highlands of Tigray and plays both as dietary and income generating. The eastern and southern zones are particularly the highest potato production which accounts for more than 83% of total area and more than 74% of total production of the region with an average yield of 10 t ha⁻¹ (CSA 2003). Both crops are grown mainly independently though some farmers often undertake maize and potato intercropping due to diminishing suitable land for food production. However, the procedure is not optimized and there is a great variation on yield productivity (BOARD 2010). In the region, both crops are considered as food security crop and there is a great need to improve their productivity through intercropping.

Most studies in Ethiopia have focused on cereal and legume intercropping and identified suitable genotype combinations, plantings dates, and population densities of various species while, little attention was given to other intercropping systems (Bantie et al. 2014). Several authors have reported the superiority of maize/potato intercropping to sole (Amin et al. 1996; Sharaiha Battikhi 2002; Tesfay et al. 2006; Yayeh 2015). This suggests that the system can help to raise productivity to achieve food security but the system has never been researched and no studies have been made to improve the productivity of the system. To this effect, an experiment was conducted at Hawzen to assess the compatibility of the companion crops and identify best cropping ratio that maximize land use efficiency.

## 2 Objectives

- To assess the compatibility of companion crops.
- To identify the best cropping ratio that gave land use advantages of the component crops in intercropping system.

## 3 Materials and Methods

### 3.1 Site description

The experiment was conducted during the 2012 cropping at Hawzen district. Geographically, the site is located at 39° 27’ 2” E and 13° 15’ 16” N, altitude of 2120 meters above sea level. The long term average (1971-2000) annual precipitation was 536 mm while the total rainfall of the growing season was 469 mm. The average minimum temperature was 10°C and maximum temperature was 27°C. The study has a one season rainfall pattern with an extended rainy season from March to November with the peak season in August. The area has a mixed farming system with crop dominance. The dominant crops growing in the area are wheat, maize barley, teff and vegetables mainly potato and tomato. The soil of the experimental site was sandy loam in texture (Rowell 1994). According to rating of Tekalign (1991), the soil was almost neutral (6.3) and low in total nitrogen (0.05%), low available Olsen P (5.45ppm) and medium in CEC (20 mq/100g soil).

### 3.2 Experimental design and treatments

The field experiment was laid out in a randomized complete block design with three repeats. The treatments consisted three intercropping combinations viz: two rows of maize + one row of potato, one row of maize + one row of potato, one row of maize + two rows potato, maize only and potato only. The maize variety used was Melekasa II and Gera for potato. Both potato and maize were sown at the same time in rows 75 cm apart with 25 cm intra-row spacing based on the required treatment. Maize seeds were sown at the rate of two seeds per hill and the seedlings thinned to one plant per hill after three weeks. Recommended hand weeding and harvesting practices were followed, and fertilizers were applied at rates of 50 kg urea and 100 kg Dap ha⁻¹ for maize and 195 kg Dap ha⁻¹ and 165 kg urea for potato.

#### 3.2.1 Treatments tested

1. Two rows of maize planted with one rows of potato (maize was planted in 75 cm × 25 cm and distance between potato and maize is 37.5 cm) (2 maize: 1 potato).
2. Potato was planted between rows of maize (maize planted in 75 cm × 25 cm) (1 maize: 1 potato).
3. One row of maize planted with two rows of potato (potato was planted in 75 cm × 25 cm and distance between potato and maize is 37.5 cm) (1 maize: 2 potatoes).
4. Maize only.
5. Potato only.
3.3 Data collection and measurements

Data on plant height, cobs per plant, cob length, and tubers per plant were determined from 10 randomly sampled plants per plot during physiological maturity. The grain and tuber yield of each crop of the component crop in the intercrop was determined from the harvestable plot and converted to tones ha⁻¹.

3.4 Data analysis

Data was subjected to analysis of variance (ANOVA) following statistical procedures of SAS version 9.2. The level of significance was set at (p ≤ 0.05). Whenever treatment effects were significant, the means were separated using Duncan’s multiple range tests.

The land use efficiency was calculated. The land equivalent ratio is considered a measure of the efficiency of grain or economic yield of the crop in mixture, compared with sole crops, and based on land use. LER indicates the efficiency of intercropping for using the resources of the environment compared with mono-cropping (Mead and Willey 1980). The LER was calculated as follows: (Willy and Osiru 1972)

\[
\text{Land equivalent ratio (LER)} = \frac{\text{YAB}}{\text{YAA}} + \frac{\text{YBA}}{\text{YBB}}
\]

Where:

- \( \text{YAB} \) = yield of crop A (maize) when intercropped with crop B (potato),
- \( \text{YBA} \) = yield of crop B (potato) when intercropped with crop A (maize),
- \( \text{YAA} \) = yield from sole planted crop A (maize),
- \( \text{YBB} \) = yield from sole planted crop B (potato).

A LER of 1.0 would indicate that the amount of land required for both crops in the different pattern was the same as that for each crop grown individually. It is also an indicator of complementary of the component crops. This would imply that there was no advantage of intercropping over pure crops. An LER greater than 1.0 would show a yield advantage of intercropping over pure crops. In contrast, when LER is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures (Ofori and Stern 1987).

4 Results and discussion

4.1 Maize component

The plant height, number of cobs plant⁻¹, cob length and grain yield under the different treatments are shown in Table 1. Both cob plant⁻¹ and cob length were not significantly influenced by the different treatments while plant height and grain yield were significantly (P<0.01) influenced by the treatments. Plant height was the highest in sole cropping, 28% taller compared to the intercropping treatments that consist of one row of maize and two rows of potato intercropping ratio (Table 1). The increase in plant height under sole cropping might be attributed to the absence of other species competition for growth resources.

Likewise, the grain yield of maize was significantly (P<0.01) influenced by the effect of treatments as such it was the highest under sole cropping (4.7 t ha⁻¹) followed by two rows of maize intercropped with one row of potato (4.4 t ha⁻¹) which resulted in an increase of 28% and 20% as compared to intercropping treatment that consists of one maize and one potato row arrangement (3.6 t ha⁻¹). The yield increase under sole cropping as opposed to intercropping treatments might be attributed to the highest plant population and decrease in inter competition among plants.

The combined mean data presented in Table 1 showed significant yield advantage for 2 maize:1 potato planting arrangement compared to the other intercropping treatments according to the productivity of maize plants,
which reached 4.41 ton/ha, compared to 3.66 ton/ha in 1 maize:2 potato planting pattern which might be attributed to the decreased inter and intra competition between potato and maize. The increased yield for this treatment resulted in the low density of potato plants per unit area which allowed maize plants to get a greater domain, for large biological activity compared with maize in the two potato and one maize arrangement, where there was a high density of potato plants.

The partial land equivalent ratio of maize in the intercropping system were significantly (P<0.01) influenced by maize / potato intercropping arrangements (Table 3). The highest PLER of 0.94 was recorded for two rows of maize / one row of potato compared to the 1 maize: 2 potato planting pattern (PLER = 0.78). The results revealed that an increase in maize planting ratio increased partial land use efficiency of maize in either of the intercropping patterns. The results of this study are in agreement with Yilmaz et al. (2001) and Yayeh (2015).

### 4.2 Potato component

Plant height, tuber per plant and tuber yield under the different treatments is shown in Table 2. Plant height was significantly (P<0.01) influenced by the planting ratio. The greatest plant height was potato only which resulted in an increase of 28% over one maize/one potato row arrangement which resulted in the shortest plant height (91.7 cm).

Intercropping maize-potato in different spatial arrangement significantly affect potato tuber yield (P<0.01). There was a significant increase in productivity of sole cropped potato (34.3 t ha⁻¹) compared with the intercropped treatments which ranged from 14 to 27 tons ha⁻¹. The lowest potato mean tuber yield was obtained at 2 maize: 1 potato (14.09 tons ha⁻¹). The reduction ratio of potato productivity in 2 maize: 1 potato arrangement was 59% compared to the sole cropped potato arrangement due to low plant population per unit area.

The combined mean data presented in Table 2 shows that there is an advantage to 1 maize:2 potato over other intercropping treatments according to the productivity of potato plants, which reached 27.82 ton/ha, compared with 14.09 ton/ha in 2 maize:1 potato. This significant increase in potato yield was attributed to the decreased inter and intra competition between potato and maize; and potato plants, which resulted from low density of maize plants per unit area that allowed potato plants to get a greater domain, which is needed for large biological activity compared with potato under 2 maize: 1 potato intercropping arrangements, were there was a high plant density of maize plant. The results are in agreement with Ebwongu et al. (2001) who reported that productivity of the potato crop decreased when intercropped with maize compared to the plantation of potato only, while it increased by increasing plant density during intercropping treatments.

The partial land equivalent ratio of potato in intercropping systems were significantly (P<0.01) influenced by maize / potato intercropping arrangements (Table 3). The highest PLER (0.80) was resulted from one row of maize / two rows of potato compared with 0.41 for the 2 maize: 1 potato planting pattern. The results revealed that increase in potato planting ratio increased partial land use efficiency of potato in either of the intercropping patterns. The results are in agreement with Ebwongu et al. (2001) who reported that productivity of the potato crop decreased when intercropped with maize compared to the planting potato only while it increased by increasing plant density during intercropping treatments. The trend implies that an increase in the number of rows of potato increased tuber yield showing flexibility for variation in potentiality for intensification of cropping. Similar findings were reported by Yilmaz et al. (2001), Sharaiha et.al. (2004), Tesfay et al. 2006 and Yayeh (2015).

<table>
<thead>
<tr>
<th>Treatment combination</th>
<th>PL ht (cm)</th>
<th>Tuber / plant</th>
<th>Yield t ha⁻¹</th>
<th>PLER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two rows maize/one row potato</td>
<td>91.70ᵇ</td>
<td>11.33ᵃ</td>
<td>14.09ᵈ</td>
<td>0.41ᶜ</td>
</tr>
<tr>
<td>One row maize/one row potato</td>
<td>97.33ᵇ̅</td>
<td>10.20ᵃ</td>
<td>18.22ᶜ</td>
<td>0.53ᵇ</td>
</tr>
<tr>
<td>One row maize/two rows of potato</td>
<td>109.37ᵇ</td>
<td>11.17ᵃ</td>
<td>27.82ᵃ</td>
<td>0.80ᵃ</td>
</tr>
<tr>
<td>Potato only</td>
<td>117.23ᵇ</td>
<td>12.03ᵃ</td>
<td>34.36ᵃ</td>
<td>1ᵃ</td>
</tr>
<tr>
<td>Cv%</td>
<td>10.4%</td>
<td>16.2%</td>
<td>6.78%</td>
<td>6.4%</td>
</tr>
</tbody>
</table>

Values followed by the same letter in a column are statistically similar at 0.05% level according to Duncan’s multiple range tests, pl.ht= plant height, PLER= partial land equivalent ratio.
4.3 Combined yield

The combined yield of maize and potato in intercropping systems were significantly (P<0.01) influenced by the intercropping arrangements (Table 3). The highest combined mean yield of the component crops (31.11 t ha⁻¹) was obtained from one maize: two potato rows followed by one maize: one potato row planting pattern with a yield of 22.20 t ha⁻¹ (Table 3). The highest yield in the former intercropping treatment could be attributed to growing spaces being varied; temporal growth variance between two varying crops; a combined increase in making better use of light, soil moisture content and nutrients as discussed by Jamshidi et al. (2007). The highest yield in intercropping as opposed to sole cropping was supported by several studies (Amin et.al (1997), Sharaiha et.al. (2004), Tesfay et al. (2006), Temesgen and Wondimu (2012) and Yayeh (2015).

Partial LERs for potato and maize grown in the intercropping systems are less than unity (Table 3) indicating that both maize and potato are compatible for intercropping under different cropping intensities. The highest PLER for potato (0.80) was recorded for one row of maize / two rows of potato compared with (0.41) in the 2 maize:1 potato planting pattern. Likewise, the highest PLER for maize (0.94) was recorded from two rows of maize / one row of potato compared with (0.78) in 1 maize:2 potato planting pattern. Partial equivalence of either crop increased as equivalence of the other component decreased.

4.4 Land Equivalent Ratio (LER)

Total LER were significantly (P<0.01) influenced by intercropping arrangements (Table 3). Total LER was significantly different from 1.00 in all intercropping treatments, which shows an advantage over pure stands in terms of the use of environmental resources for Plant growth as reported by Mead and Willey (1980).

In this study, TLER ranged from 1.35 to 1.58. The combined yield advantage in terms of total LER indices was greatest in the cases of 1 maize: 2 potato intercropping arrangement (1.58) which might be attributed to more efficient total resource exploitation and greater overall production as opposed to the other intercropping treatments. This indicated that additional 0.58 ha (58%) more area would have been needed to get equal yield to planting maize and potato in pure stands. This result is in agreement with the findings of several other intercropping studies (Minale et al. 2001; Javanmard et al. 2009, Temesgen and Wondimu 2012) who demonstrated the advantages of intercropping systems where, LER of greater than 1 was recorded. This might indicate that in a suitable combination plants can complement each other in a more efficient use of environmental resources, mainly light, water and nutrients (Willey, 1979). The current intercropping systems demonstrate that farmers could benefit by growing the companion crops with different cropping intensity in the dry lands of Tigray.

5 Conclusion and Recommendation

The experimental results have demonstrated that the sole planting of either maize or potato results in maximum crop yield. The results imply that yield increased with increased population density of the component crops, the corresponding reduction in plant density for intercropping therefore leads to a reduction in yield.

Though the reduction in plant density of each component crops led to a reduction in yield of both crops as evidenced by the partial LER (<1), the total yield of intercropped crops were greater than sole cropping as shown by TLER which were more than unity (TLER>1). This indicates the cohesiveness of the component crops under intercropping.

<table>
<thead>
<tr>
<th>Planting pattern</th>
<th>Combined yield t ha⁻¹</th>
<th>PLER M</th>
<th>PLERP</th>
<th>TLER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two rows maize/one row potato</td>
<td>18.50</td>
<td>0.94ab</td>
<td>0.41a</td>
<td>1.35b</td>
</tr>
<tr>
<td>One row maize/one row potato</td>
<td>22.20</td>
<td>0.85b</td>
<td>0.53b</td>
<td>1.38b</td>
</tr>
<tr>
<td>One row maize/two rows of potato</td>
<td>31.11</td>
<td>0.78a</td>
<td>0.80a</td>
<td>1.58a</td>
</tr>
<tr>
<td>Maize only</td>
<td>-</td>
<td>1a</td>
<td>---</td>
<td>1a</td>
</tr>
<tr>
<td>Potato only</td>
<td>-</td>
<td>----</td>
<td>1a</td>
<td>1a</td>
</tr>
<tr>
<td>CV%</td>
<td>7.4</td>
<td>6.4%</td>
<td>3.9%</td>
<td></td>
</tr>
</tbody>
</table>

Values followed by the same letter in a column are statistically similar at 0.05% level according to Duncan’s multiple range tests, PLERM= partial land equivalent ratio maize, PLERP= partial land equivalent ratio potato .TLER= total land equivalent ratio.
In this study, one maize and two potato row arrangement had showed 58% yield advantage over the sole cropping. This means 58% more land is needed in sole cropping of the two crops to produce the same yield as compared with their cultivation in an intercropping system. At Hawzen, maize and potato are the most adaptable and major crops as food, and cash crops. Both crops are of equal importance to the farmer because they can gain comparable economic returns, or can satisfy subsistence requirement equally. Given the unpredictable rainy season and the different water requirements of each crop, planting maize and potato together gives the farmer a better chance that either crop will survive.

Thus, the study recommended that 1 maize: 2 potato intercropping can be taken as a viable agronomic option in intensifying crop production. The implication of the results of this study is that the agricultural policy makers and bureaus of agriculture in the region should encourage farmers to produce both crops as intercrop as an option to solve food security in the region.

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