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Productivity of Irish potato varieties under increasing nitrogen fertilizer application rates in Eastern Rwanda

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Irish potatoes are an important crop only promoted in cool and high moist conditions of Rwanda. This study explored the productivity of Irish potatoes varieties under increasing nitrogen fertilizer applications in drier agro-climatic conditions of the eastern Rwanda. Potato seeds mass-selected from locally-grown varieties in the region surrounding Kibungo town (-2.160897°, 30.543591°) were planted under rain-fed conditions, during the March to June agricultural season of 2015, in the three experimental farms of the University of Kibungo at Karenge, Mugesera and Rwamagana, respectively located in Kibungo town, 30 km West and 50 km North of Kibungo town. The most performing three varieties were tested again in 2016A season (October to January, 2016) at Kibungo and Rwamagana. For each season, and at each farm, four nitrogen application rates (0, 60, 120, and 180 kg N ha⁻¹) were tested. Phosphate and potash were supplied in sufficient amounts of 150 kg P²O₅ ha⁻¹ and 60 kg K₂O ha⁻¹, respectively. No fertilizers were applied on the control treatment. A split plot design and three replicates were used with varieties in main plots and nitrogen in sub-plots. Plant growth rate, shoot counts, tuber calibration, and total and market potato tuber yields were monitored. Four varieties yielded 10 tons ha⁻¹ or more of total potato tuber yields in 2015B season. Three of them, namely Kirundo, Gasore, and Peko varieties, were re-tested in 2016. Over the two seasons, Kirundo variety stood out with 12.8 and 10.5 tons ha⁻¹ of total and marketable tuber yields, respectively. All the varieties significantly responded to nitrogen fertilizer. However, Kirundo variety, respectively yielded 22 tons and 17 tons ha⁻¹ of total and market potato tuber yields under 120 kg N ha⁻¹ during the 2016A season. Irish potato can therefore be grown and produce substantial yield in eastern Rwanda, provided that appropriate nitrogen fertilization and seed quality are available.

Key words: Irish potatoes, varieties, nitrogen, yields, fertilizer, rates.

INTRODUCTION

The Crop Intensification Program (CIP), initiated in September, 2007 across Rwanda, has focused on six priority crops namely Maize, Rice, Banana, Beans, Cassava, and Coffee in the Eastern Province (MINAGRI, 2008).

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The selection of these crops was based on the agro-ecological zones established in the mid-seventies (Delepiere, 1974) and continuously referred to (Verdoort and van Ranst, 2003; MINAGRI, 2010) with no update with regard to climate change impact and adaptation strategies. Consequently, under CIP, Irish potatoes have been promoted in northern and western regions of Rwanda while the eastern region has been considered marginal for this crop (REMA, 2009). In that regard, it was assumed that Irish potatoes required cooler and higher moisture conditions to achieve optimum yields. In terms of drought susceptibility, the risks increase from West to East of the province. This drought susceptibility also varies with the season (MIDMAR, 2014), from very low to moderate in Season A (October to January) and moderate to high in Season B (March to June). Despite these conditions, at community level, Irish potatoes are grown in eastern Province in both seasons. However, with no financial support of Government programs, yields have remained very low, from 3.5 to 6.5 tons ha⁻¹, compared to 12 to 15 tons ha⁻¹ for the regions under the Government assistance (MINAGRI, 2014).

Scattered research reports have shown that the applications of 30 tons of manure and 50 kg ha⁻¹ of each of N, P₂O₅ and K₂O actually recommended on Irish potatoes did not result in optimum tuber yields for Cruzza potato variety grown in two suitable agro-ecological zones (Turamyeniyirijuru, 2013). In fact, harvested total potato tuber yields varied from 13.8 tons ha⁻¹ in Nyaruguru, southwest Rwanda, to 17 tons ha⁻¹ in Kinigi, northern Rwanda. On the contrary, nitrogen application rate in the amount of 140 kg N ha⁻¹ on Kinigi potato variety resulted in yields varying from 31 to 37.7 tons ha⁻¹ of tubers (Nyiransabimana, 2011) in Busogo (northern Rwanda) while more than 42 tons ha⁻¹ were harvested from the application of 150 kg N ha⁻¹ on the same Kinigi potato variety in Kinigi area, same region (Fashaho et al., 2013). Therefore, potato yields remain dependent on the weather conditions, even when it is grown in recommended regions.

Otherwise, previous findings on potatoes crop have pointed out that nitrogen management was an important challenge, economically and environmentally (Zebarth et al., 2007; Karemangingo et al., 2007). Several studies indicated that, depending on the varieties, potatoes usually required more than 100 kg N ha⁻¹ to yield 30 tons ha⁻¹ or more of tubers under rain-fed conditions (Zebarth et al., 2007; Barascu et al., 2015; Getie et al., 2015). It appeared therefore that a better control of nitrogen fertilization of potatoes was needed before any conclusion can be made on the potential of the eastern Rwanda for Irish potatoes production. This study therefore aimed at evaluating the yield potential of the most commonly grown Irish potatoes varieties in eastern Rwanda under increasing nitrogen fertilizer application rates with the view of promoting the production of Irish potatoes in this region.

**MATERIALS AND METHODS**

**Site characteristics**

This study was conducted in the Eastern Province of Rwanda for two agricultural seasons: from March to June, 2015 (or 2015B season) and from October to January, 2016 (or 2016A season). It was undertaken on three experimental farms of the University of Kibungo: at Kibungo (-2.160897°, 30.543591°), near the main Campus of the University (1680m asl), at the Mugesera Lake shore (1350m asl), about 30 km West of Kibungo, and at Rwamagana town (1528m asl), 50 km North of Kibungo and 40 km East of the Kigali City. The rainfall pattern of the study area follows a bimodal type with the average precipitation amount of 986.7 mm per annum, a major peak in April (B Season) and a small one in October – November (A Season). The mean minimum, maximum and average temperatures are 13.5, 27.2 and 19.5°C in Kibungo (www.weatherspark.com/kibungo) and 13.8, 27.6, 22.6°C in Rwamagana, (www.weatherspark.com/rwamagana), respectively. No such information is available for the Mugesera farm; but the conditions are very similar. The soils of the region are mainly Ferralsols (Oxisols) depleted in clay and organic matter as a result of continuous cultivation and water erosion (Nzejimana et al., 2014). The Karenghe experimental farm is located on a 5% slope loam soil, the Musesera site on a 5% slope sandy loam soil, and the Rwamagana site is on a 2% slope sandy-clay loam soil.

**Treatments and experimental design**

**Genetic materials**

Healthy potato plants were selected and harvested from different farmers’ fields of the region in the 2015A season. The harvested potato varieties included Gasore, Kruzza and Mabondo varieties for Kibungo site, Kruzza, Makara, and Peko for the Mugesera site, and Gasore and Mabondo for Rwamagana site. A third variety for this Rwamagana site was the Kirundo potato variety graciously supplied by Rwanda Agricultural Board (RAB) from their Office of Musanze (North Province). Harvested plants could not supply sufficient potato seeds for all sites. Therefore, although six varieties were harvested and tested, only three varieties were tested at each site. No fungicide treatment was applied on the seeds. The study was continued in the 2016A season with the best performing potato varieties from 2015.

**Nitrogen fertilization**

Four nitrogen fertilizer application rates were supplied from 0 to 180 kg N ha⁻¹ with a 60 kg N increment from a blend (17-17-17) and urea (46-0-0). Phosphorus and potassium were applied from the same blend (17-17-17) and triple superphosphate (0-46-0) to supply 150 kg P₂O₅ ha⁻¹ and 60 kg K₂O ha⁻¹ over all the experimental units, but the control. These amounts of N, P₂O₅ and K₂O were applied on all the potato varieties at each site.

**Experimental design**

A split plot design and three replicates were used. The potato varieties were tested in the main plots while the effects of nitrogen fertilizer application rates were tested in the sub-plots. Each subplot was 3.6 m wide × 4.0 m long; the plant spacing was 90 cm between rows and 40 cm within each row. Fertilizers were manually band-applied in the trench below the seeds and slightly covered by the soil before planting. Hilling and weed control operations were also manually done. Dithane M 45 was applied a couple of times in
2015 to control fungi development on leaves at Kibungo and Rwamagana.

Evaluation of the effects of treatments

Data collection was done from the two central rows of each plot for growth parameters. Collected data included plant emergence counts, plant growth rate through measuring plant height at different dates after planting, number of plants and shoots at harvest. For yield evaluation, the whole plot was considered for tuber calibration as follows: small size tubers (lower than 10 cm of circumference), medium size tubers (from 10 cm to 15 cm of circumference), big size tubers (above 15 cm of circumference), tuber quality (rough and rot tubers, hollow heart tubers), and total and market potato tuber yields. Statistical analyses were performed using NCSS software package (Hintze, 2004) and mean yields compared using Duncan's multiple range test (DMRT). All statistical analyses were performed site by site and by season/year. The test signification was considered at 5% probability level.

RESULTS AND DISCUSSION

Comparative performance of different potato varieties

During the 2016 season, Kirundo and Peko varieties had no significant difference in sprout rates (respectively 94.2 and 89.2%) 30 days after planting, and no significant difference in growth rate, 60 days after planting (respectively 53.4 and 59.7 cm plant height). All the potatoes varieties had equal shoot numbers with an average of 4.3 shoots by planted tuber as monitored at harvest. No significantly different effects were detected with regard to nitrogen fertilizer application rates on the sprout and growth rates as monitored 30 and 60 days after planting. With regard to the tuber numbers by size grade, the results on the yield performance of potato varieties over the two seasons (2015B and 2016A) indicated significant differences between the three varieties tested in Kibungo in 2015 (P < 0.05) with regard to the size of the tubers. Although the number of small size tubers was high for Kruza, this variety stood out with 173,800 market potato tubers against 127,600 and 112,000 tubers for Gasore and Mabondo, respectively. At Rwamagana, Kirundo and Mabondo varieties yielded equal market potato tuber numbers (154,700 and 131,800 tubers, respectively), but significantly higher (P < 0.01) than Gasore potato variety (77,600 tubers). At Mugesera, all the three varieties yielded equal numbers of tubers for each tuber size grade. In 2016, Kirundo potato variety yielded equal numbers of market potato tubers as Peko; the two varieties yielded twice and thrice as much as Gasore (58,700 tubers), respectively.

The results related to the yields are presented in Table 1 by grade, total and market tuber by site. Kirundo potato variety at Rwamagana and Peko variety at Mugesera significantly yielded much higher than the two other varieties tested at the same time in each site in 2015. All varieties that yielded 10 tons ha⁻¹ of market potato tubers in 2015 were selected for subsequent tests in 2016 season. The results obtained in 2016 confirmed the higher performance of Kirundo variety in comparison to the other varieties in the two sites, Kibungo and Rwamagana. It yielded more than 10 tons/ha of total and/or market potato tubers, particularly due to medium and big size potato tuber yields. Peko variety reasonably sustained a high yield although lower than Kirundo. It is important to note that locally-selected varieties could have lost their production potential over the years and this could explain their lower yield performance when compared to Kirundo potato variety.

Overall, however, all the varieties yielded much lower than their potential (above 30 tons/ha) (MINAGRI, 2010) under rain-fed conditions (Getie el al., 2015; Fashaho et al., 2013). They are however in the range of national average yields of 10.0 to 12.5 tons potato tubers ha⁻¹ (MINAGRI, 2011; RAB, 2014). Most importantly, compared to promoted crops for Eastern Province such as rice and maize, Irish potatoes appear potentially very competitive for both yields (NISR, 2016) and profitability for the growers (GoR, 2013).

Comparative effects of nitrogen fertilizer application rates on potato yields and yield components

With regard to the plant potato sprout rates, no significant differences were observed between the different rates of nitrogen fertilizer. Significant differences detected with regard to plant growth rate as measured by the plant height 30 and 60 days after planting only indicated higher growth for all nitrogen application rates than the control, regardless of the season/year.

With regard to the number of tubers per grade, the numbers of medium and big tubers were always higher with higher application rates of nitrogen fertilizer, regardless of the season/year. Total tuber numbers were significantly equal from 120 kg N ha⁻¹ (228,200 tubers) and 180 kg N ha⁻¹ (232,100 tubers) but higher than from 60 kg N ha⁻¹ (181,700 tubers) and the control (135,500 tubers) in 2015 at Kibungo site. Similar trends were observed for the other sites. The same was also true for the numbers of market potato tubers. The impact of bad weather conditions in 2016 explains the increase of small and rough tubers and the decrease of the numbers of market tubers comparatively to total tuber numbers. In this respect, at Kibungo, the numbers of market potato tubers represented 51.7 and 47.9% of total potato tuber numbers under 120 kg and 180 kg N ha⁻¹, respectively. At Rwamagana, the market potato tuber numbers represented 68.4 and 59.9% of total potato tuber numbers under similar N application rates, respectively. In the two sites, the N application rate in the amount of 120 kg ha⁻¹ constantly yielded higher or equal tuber numbers than 180 kg N ha⁻¹. This latter and 60 kg N ha⁻¹ yielded significantly equal numbers of tubers.
Nitrogen application rates have significantly increased total and market yields at all sites comparatively to the control. However, the three N rates significantly increased total and market yields at all sites and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields.

The same was true in the 2016 at Kibungo (P<0.05) and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields. Nitrogen application rates had no significant effects on yield levels in 2015 and Rwamagana (P<0.001) for each of total and market potato tuber yields.

The same was true in the 2016 at Kibungo (P<0.05)
Table 3. Mean yield responses of different potato varieties to increasing nitrogen fertilizer application rates in 2016.

<table>
<thead>
<tr>
<th>Farm</th>
<th>Nitrogen application rates (kg N/ha)</th>
<th>Small tuber (Tons/ha)</th>
<th>Medium size (Tons/ha)</th>
<th>Big size tuber (Tons/ha)</th>
<th>Rough and rot (Tons/ha)</th>
<th>Total yields (Tons/ha)</th>
<th>Market yields (Tons/ha)</th>
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</thead>
<tbody>
<tr>
<td>Kibungo</td>
<td>0</td>
<td>1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.4&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>60</td>
<td>1.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.8&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>120</td>
<td>2.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.0&lt;sup&gt;b&lt;/sup&gt;</td>
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<td></td>
<td>180</td>
<td>2.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Rwamagana</td>
<td>0</td>
<td>1.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;a&lt;/sup&gt;</td>
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Yield levels suffixed with different letters are significantly different by site and season-year.

13.6 and 10.0 tons ha<sup>-1</sup> at Kibungo and 14.0 and 12.1 tons ha<sup>-1</sup> of potato tubers at Rwamagana, respectively. Big size tuber yields (>15 cm circumference) represented 63 and 57% of market yields at the two respective sites under 120 kg N ha<sup>-1</sup>; the balances compose medium size potato tubers or seed potatoes.

The nitrogen application rate in the amount of 120 kg ha<sup>-1</sup> has constantly yielded equal to or higher than the amounts of 60 kg and 180 kg N ha<sup>-1</sup>. Over all sites, varieties, and seasons, the application of 120 kg N ha<sup>-1</sup> has resulted in average yields of 11 tons and 8.8 tons ha<sup>-1</sup> of total and market potato tuber yields, respectively. This represents 1.87 times yield increase compared to when controlled. Similar potato tuber yields were also harvested from suitable agro-ecological zones for Irish potatoes (Turamyeniyirjuru, 2013; Fashaho et al., 2013; Nyiransabimana, 2011). Worldwide, under non-irrigated conditions, Irish potatoes nitrogen requirement usually varies from 100 kg ha<sup>-1</sup> for early maturing varieties to more than 200 kg N ha<sup>-1</sup> for late maturing ones and for more than 30 tons ha<sup>-1</sup> of market tuber yields (Getie et al., 2015; Barascu et al., 2015; Zebarth et al., 2007). The eastern Rwanda can therefore grow Irish potatoes and expect as good yields as elsewhere in Rwanda, and probably more under irrigation.

**Comparative potato variety responses to nitrogen fertilizer application rates**

Over the two seasons of the study, significant interaction effects were detected between potato varieties and N application rates at Kibungo site with regard to total and market potato tuber yields. The same also happened at Mugesera in 2015. No such interaction effects were observed in Rwamagana over the two agricultural seasons. In 2015 at Kibungo, Mabondo and Kruza varieties, respectively reached their maximum yields with 60 kg and 120 kg N ha<sup>-1</sup> while no maximum potato tuber yield was achieved for Gasore variety on this site (Figure 1). Although no significant interaction effects were observed in Rwamagana, there is a constant trend for potato varieties to specifically respond to increasing nitrogen application rates, with Gasore and Kirundo yielding highest at around 120 kg N ha<sup>-1</sup> while the highest yield for Mabondo was at 60 kg N ha<sup>-1</sup>. At the Mugesera site, the Peko variety yielded the maximum with 120 kg N ha<sup>-1</sup> while the yields of the other two varieties were highest with 60 kg N ha<sup>-1</sup> (Figure 2). In 2016, the Kirundo potato variety continuously stood out with 22 tons ha<sup>-1</sup> of total potato tuber yields from the application of 120 kg N ha<sup>-1</sup> (Figure 3). Market potato tuber yield was slightly higher than 17 tons ha<sup>-1</sup> under the same amount of nitrogen fertilizer.

Potato varieties differently responded to nitrogen fertilizer application rates. Previous findings on the responses of different potato varieties to nitrogen fertilizer application rates indicated optimum amounts varying from 100 to 200 kg N ha<sup>-1</sup> for yields varying from 27 to 47 tons ha<sup>-1</sup> (Shunka et al., 2017 and Barascu et al., 2015). Otherwise, upon 130 to 190 kg N ha<sup>-1</sup> yields varying from 20 to 25 tons ha<sup>-1</sup> potato tubers were harvested (Manorama et al., 2012). Rens et al. (2015) found peak potato marketable yields with 112 kg ha<sup>-1</sup> applied at emergence time. Kirundo yield around 20 tons ha<sup>-1</sup> under the application of 120 kg N ha<sup>-1</sup> is within these ranges. Higher N rates resulted in higher potato yields in Zimbabwe (Mutubuki et al., 2015) and Ethiopia (Zewide et al., 2012). But, the absence of interaction effects between potato varieties and nitrogen fertilizer application rates has also been documented (Rykbost and Charlton, 2000). Therefore, the nitrogen fertilizer application in the
amount of 120 kg N ha\(^{-1}\) is within the range of many findings worldwide.

**Conclusion**

This factorial experiment explored the productivity of Irish potatoes in the agri-climatic conditions of the Eastern Province of Rwanda, comparing potato tuber yields and yield components of mass-selected, locally-grown potato varieties under increasing nitrogen fertilizer application rates. The results have indicated that Irish potato varieties can be grown and yield as much as they do in regions assumed more suitable for the crop in Rwanda. Yields
from 10 tons to more than 17 tons ha$^{-1}$ of market potato tubers were harvested. Irish potato varieties have responded differently to nitrogen fertilization. However, nitrogen application rate in the amount of 120 kg N ha$^{-1}$ has constantly resulted in highest yields, particularly with Kirundo variety. Therefore, 120 kg N ha$^{-1}$ should be recommended for expected yields above 20 tons ha$^{-1}$ of market potato tubers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

REFERENCES


