Assessment of Opportunities for Burundian Small-Scale Potato Farmers to Increase Productivity and Income

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Abstract

From 2014 through 2016, on-farm experiments were carried out in three provinces surrounding Bujumbura town in Burundi to improve the low potato (*Solanum tuberosum*) yields, which currently stand at about 6 t ha^{-1}. It was hypothesised that in rain-fed conditions, improved varieties, healthier seed tubers, pre-sprouting in light, proper fertilisation and protection from late blight attack would improve yield and quality, such as tuber weight, tuber size and lower brown rot incidence. The treatments in the on-farm trials at five farms in each of three sites (15 replicates) were applied in two seasons, giving 30 replicates in 580 plots. The following treatments were compared with growers' current practices: introduction of two new varieties, use of early generation seed from a rapid multiplication scheme, earlier harvesting of a seed crop, seed storage in a diffused light store, and research-based timing and dose rate of fertilisers and fungicides. Marginal rates of return on investments were calculated at farm level and current and tested alternative technologies were compared. Costs and benefits of applying such techniques were calculated. An improved variety contributed up to 20% yield increase and healthier seed 80%. Early harvesting reduced yield by 30% and reduced incidence of brown rot in the current season, but increased it (from 21 to 39%) in the following season when tubers were replanted. Diffused light storage, alternating contact and systemic fungicide application, and application of chemical fertilisers resulted in 30, 50 and 60% yield increases, respectively. It was shown that it is possible to double yields and economic returns (marginal rates of return) under the growing conditions in Burundi when growers plant healthy pre-sprouted seed of a new variety and apply chemical fertilisers and fungicides.

Keywords

Acceptable minimum rate of return
Chemical fertilisers
Diffused light store

Fungicides
Healthy seed tubers
Marginal rate of return
New potato varieties
On-farm trials

Introduction

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Farmers constantly make adjustments in their farms to smooth operations and to increase productivity and profitability. These choices involve actions to optimise productivity and the financial return of the farm while mitigating the effects of unfavourable conditions or events such as disease pressure, drought or changes in the market conditions. Some of these decisions are relatively simple requiring choices among various practices and profitable innovations within their enterprise.

Potato (*Solanum tuberosum* L.) is an important food and cash crop in Eastern and Central Africa (ECA). Its importance continues to rise due to increased urbanisation and uptake of processed potato products such as French fries (chips) and crisps. According to FAO data (FAOStat 2016), the tuber crop is ranked 2nd in Kenya and Rwanda, 6th in Burundi and 10th in Uganda.

Table 1 shows the development of potato production in Central and Eastern African countries by giving production data for 1982 and 30 years later for 2012. On average for the whole region, the population increased two-and-half-fold and potato production increased almost sixfold, resulting in an increase in per capita production from 13 to 30 kg per person. Consumption is some 20% less as part of the crop is used as seed for the next season and some losses occur. Statistics in general underestimate production as not all crops are recorded. Usually, only the main planting season is recorded, but in the whole region two or even three crops are grown per year. The most noticeable production increase took place in Rwanda with an almost ninefold increase of tonnage following a more than fourfold increase in area and a more than doubling of yields.

Table 1

Some potato data in Eastern and Central African countries (FAOStat, Worldometer, and Factfish)

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Country	Area × 1000 ha		Yield t per ha		Production per year × 1000 t		Population millions		Per annum kg per capita	
	1982	2012	1982	2012	1982	2012	1982	2012	1982	2012
Burundi	12.0	15.4	2.91	6.22	35.0	122.9	4.36	10.1	8.02	12.3
Rwanda	40.3	164.8	6.66	14.2	268.8	2338	5.49	10.8	49.0	216.5
Uganda	28.0	112.0	7.00	7.02	196.0	787.0	13.4	35.4	12.6	22.2
Tanzania	58.2	211.5	4.47	8.71	260.2	1842	19.9	48.6	13.1	37.9
Kenya	76.0	143.3	6.55	20.3	498.1	2921	17.6	42.5	35.2	68.7
DR Congo	5.4	22.5	5.00	7.70	27.0	173.2	27.7	70.3	0.97	2.46
Ethiopia	43.0	74.9	8.0	11.5	334	863.3	37.1	92.2	9.00	9.36
Total average	262.0	754.4	5.74	10.3	1619	9047	125.9	309.9	12.86	29.19

The highest yields are recorded in Kenya with more than 20 t ha^{-1}. Also, in Tanzania, yields almost doubled but in the other countries they more or less stagnated. The yield increases over the 30-year period can be attributed to the introduction of new varieties, mainly by the International Potato Center (CIP), and by the increased use of fungicides and fertilisers that were hardly available in the early 1980s. A considerable gap exists between on-farm potato yields of 10 t ha^{-1} (Kaguongo et al. 2008) and those that can be attained under improved growing circumstances, where 40 to 60 t ha^{-1} is achievable (Raemaekers 2001). The low yields are attributed to both biotic and abiotic stresses and to poor management practices. Poor quality of seed tubers used by farmers is viewed as a major yield-limiting factor (Gildemacher et al. 2009), a major reason being own-saved tubers from previous harvests or sourced from markets or neighbours (Barton et al. 1997). Such tubers are often of poor health status owing to latent infections of *Ralstonia solanacearum* (causal agent of bacterial wilt and brown rot of tubers), viruses and other tuber-borne pathogens (Kinyua et al. 2001).

Studies (Kaguongo et al. 2010) indicate that over 70% of farmers' fields in Burundi, Kenya and Uganda are infected by bacterial wilt. Several initiatives have been undertaken to address the challenge of unavailability of certified and quality seed potatoes in the East and Central Africa (ECA) region. In Burundi, various studies of the seed sector have been carried out during recent years in the context of international programmes such as those conducted by FAO and the Belgian Technical Cooperation Agency (BTC). These studies mainly focus on the organisation of the formal seed system. However, the informal seed system is almost the exclusive source of seed for ECA farmers. Little is known about its functioning, mechanisms of seed supply among farmers, sources of seed, the stability of the system over time, the varieties used, the economics and quality of informal seed multiplication and other basic information. Such information is essential in order to better target future interventions in the seed sector. The formal seed system in Burundi provides less than 1% of the seed required nationally.

The small amount of improved seed is mostly derived from the National Agricultural Research Institute of Burundi (ISABU) and the few private seed entrepreneurs supported by the BTC effort with in vitro-based rapid multiplication techniques. This yields minitubers from plants grown in insect-proof screen houses in sterilised soil, and hence devoid of tuber-borne pests and diseases. These minitubers are grown for two field generations (1 and 2) before being distributed. The potential of healthy, relatively expensive seed can only be fully realised when it is of improved varieties, well stored and sprouted, and the crop is well protected from late blight and adequately supplied with nutrients. However, the level of productivity and profitability of these improved techniques are not known.

The objective of the research, therefore, was to assess the impact of the main factors contributing to yield improvement: improved varieties, healthier seed, better stored seed, late blight control (this disease is a major reason for low yields (Lungaho et al. 2008)) and fertilisation (low soil fertility and lack of fertilisation is also a major reason for low yields (Muthoni and Kabira 2011)). This was demonstrated in on-farm trials that have the advantage of testing the technologies in real-world conditions outside the research station. Moreover, demonstrating the technologies to growers ensures rapid adoption.

Partial budgeting is a tool used to assess the costs and benefits associated with a specific change on a farm. This tool specifically focuses on the implications of the intended change in a business operation by comparing the benefits and costs resulting from implementing an alternative technology compared to the current practice.

Materials, Methods and Rationale of the Treatments

To assess the various options for improvements, a number of treatments were applied in on-farm trials, such as those demonstrated by Harahagazwe et al. (2014). Such trials were carried out on growers' fields where farmers' practices were compared with treatments that hypothetically improve yield, quality and/or costs-benefits. At each site, each farmer's field was considered a replication for each treatment and each farm contained all tested technologies.

Procedures for the On-Farm Trials

In three provinces surrounding Bujumbura (Cibitoke municipality Bukinanyana, Bubanza municipality Musigati and Bujumbura Province municipality Mugongo Manga), a site was selected where five growers volunteered to have on-farm trials in their potato fields. Each plot representing a treatment consisted of five rows spaced 80 cm apart with 10 tubers spaced at 30 cm within each row. So, each plot was 12 m^2 in area. All plots received the ISABU-recommended fertiliser and fungicide treatments except the fertiliser, fungicide and farm-saved seed comparison plots where farmers' common practices were used for comparison. At harvest, the number of harvested plants was counted (yielding percentage emergence) and total tuber weight (tuber weight calculated as tonne per hectare) and tuber number determined, allowing the calculation of average tuber weight. The tubers were graded in cohorts of < 35, 35–55 and > 55 mm and the percentage of the total tuber weight in each size category was determined (sampling variation meant they do not always add up to 100%). Finally, at harvest, the number of tubers affected by brown rot was counted to establish the proportion of diseased tubers.

In the 2015A season, the trials were planted 22–24 October 2014 and harvested 22–24 February 2015, in the 2015B season they were planted on 3 April 2015 and harvested 6–8 August 2015, and in 2016A season they were planted on 16 November 2015 and harvested on 16 March 2016. The altitude of the sites was around 2100 m above sea level with day/night temperatures on average 22/12 °C. No irrigation took place and crops often suffered from excess rainfall in the rainy seasons with average precipitation over 150 mm per month. Each treatment was compared for two seasons at three sites in five growers' fields yielding 30 replications (n = number of replications) and ample degrees of freedom for an analysis of variance. ANOVA was carried out with the statistical package GENSTAT 14th edition (SP2). Each treatment was compared with a farmer's practice in a pair of adjacent plots so that more than one farmer's practice plot was present per site. Interactions between treatments, sites and seasons were frequent but could not be attributed to conditions that growers might influence, but rather to weather and soil type, so were not taken into consideration in the Results and Discussion section. If treatments differ at $P < 0.001$, this is indicated by *** in the tables, $P < 0.01$ by **, $P < 0.10$ by * and $P > 0.10$ by ns (not significant). In total, in three seasons, 580 plots of 12 m^2 were planted, monitored, harvested and statistically analysed.

Variables that change among the technologies being evaluated were assessed and standard error difference and capital costs associated with tested technologies were evaluated as follows. Farmers' acceptable minimum rates of return were calculated as the sum of the cost of capital and returns to management. Although most potato farmers are not aware of them, or have no access to them, formal government loans exist which attract low interest. It was assumed that the interest rate on loans in the rural area of the experiments varies from 2% (government loans) to 10% (private financial services) per month, and that the period between farm land preparation and realisation of income from seed potatoes is 6 months. If the interest rate is 2%, the cost of capital is 12% (2%/month × 6 months), whereas it is 60% (10%/month × 6 months) if the interest rate is 10%. If we assume that the majority of farmers in the study area consider that a business is profitable only when it gives 100% returns to management, the acceptable minimum rate of return (AMRR) will be 112% (100 + 12) for 2 and 160% (100 + 60) for 10% interest rate per month. If we further assume that a significant proportion of farmers obtain loans at 10%, then the AMRR is 160%.

Descriptions of the Various Treatments (Table 2)

Improved Variety Until the 1980s, most of the seed used by growers was a mixture of remnants of European varieties and selections from spontaneous true potato seeds from their open pollination. In the early 1980s, the International Potato Center (CIP) introduced many genotypes of which one Mexican variety Cruza 48 was selected because of its resistance to both late blight (*Phytophthora infestans*) and brown rot (*Ralstonia solanacearum*), and its yielding ability under low input conditions. It became the most widely grown variety for those reasons and was locally named Ndinamagara ("I am healthy" in the vernacular). Meanwhile, two varieties, Victoria and Mabondo, were selected for earliness by ISABU as potentially better performing, especially when grown under higher levels of inputs such as fertiliser and protected with fungicides against late blight. Performance of the second field generation seed (G2) of Ndinamagara and Mabondo, produced at the Institute ISABU highland site Gisozi, was tested in farm trials with the institute's guidelines for late blight control and fertilisation.

Table 2

Treatments in the on-farm trials each growing season. *Ndina* Ndinamagara, *FS* farm-saved seed, *G2* generation 2 seed from ISABU

Treatment	Varieties	2015A	2015B	2016A
New variety	Ndina/FS, Mabondo/G2	×	×	
Improved seed	Ndina/FS, Ndina/G2		×	
Early harvest	Ndina/FS*, Ndina/G2, Victoria/G2	×	×	
Seed from early harvest	Ndina/FS, Ndina/G2, Victoria/G2			×
Seed from DLS	Ndina**			×
Chemical fertiliser	Ndina/G2	×	×	
Fungicide sprays	Victoria/G2	×	×	
*In 2015B only				
**Seed from ISABU multiplied once by grower and stored in the dark and in diffused light store (DLS)				

Use of Seed Potatoes of Higher Quality Farm-saved seed is usually from many unrecorded generations and quite degenerated due to accumulation of viruses and brown rot. After an uncertain number of multiplications, the impression exists that the seed does not degenerate any further and keeps a certain, albeit low, yielding ability. Seed at ISABU is produced from minitubers and grown twice in the field under ISABU supervision and scrutiny (roguing) to produce a generation 2 (G2) of relatively healthy seed tubers that are sold as basic seed to cooperatives of growers at a high price. In the on-farm trials, farmers' conventional seed was compared with G2 seed from ISABU whereby care was taken to use seed of the same age and size in the comparison.

Harvest Time of Seed Tuber Crop Premature harvesting of crops intended as seed for the following season is done 80 days after planting compared with harvesting at crop maturity (around 120 days after planting). It is assumed that when the crop is harvested well before maturity, it is exposed for less time to factors that enhance degeneration, such as viruses transmitted by aphids, but especially to the accumulation of brown rot (*Ralstonia solanacearum*) with each growing season. Another advantage of early harvest of early generation seed is that a higher proportion of the harvest is of seed size between 25 and 50 mm.

Planting Crops with Seed Harvested at Different Times in the Previous Season Seeds of the varieties Ndinamagara (both farm saved and generation 2 from ISABU) and Victoria (generation 2 from ISABU) were harvested on two occasions in the 2015B season, stored separately in diffused light stores, and planted on the same date and harvested at maturity in the 2016A season to assess yields and disease incidence.

Seed Storage in Diffused Light Farmers as a rule use the relatively small tubers left over from the previous crop as seed for the next one. This is kept in the dark in bulk in granaries, in sheds or in the house. Sprouts tend to become long and break on handling before planting. Storing in diffused light in purpose-constructed stores (Potts 1983) results in firm green sprouts that may emerge earlier and lead to more stems and higher yields than conventionally stored seed. Seeds from the same harvest were stored in both conditions (dark and light) and planted on the same day in on-farm trials.

Fertiliser Application Until the turn of the twenty-first century, synthetic fertilisers were hardly available to growers in Burundi. Although currently for sale in the trading centres in the countryside, most growers still only apply manure and compost, and if complemented with chemical fertilisers, only limited amounts and without any decision support from the industry or extension services. Some growers use manure only, others muriate of potassium and/or diammonium phosphate at unspecified doses. Extensive ISABU research in various field trials found an optimal dose for the various variety-soil type-planting season combinations of around 60–90–60 kg NPK ha^{-1}, placed at planting near the seed tuber. In the on-farm trials, farmers' conventional fertilisation practices were compared with the ISABU-recommended rate. Late blight was controlled according to ISABU recommendations.

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Fungicide Application Losses due to late blight are considerable in East African rain-fed crops (Lungaho et al. 2008). Similar to fertilisers, the use of fungicides is slowly starting in Burundi whereby growers either do not spray or spray two to three times unspecified doses of the contact fungicide mancozeb (sold as Dithane) or the systemic fungicide metalaxyl-m (sold as Ridomil), and occasionally (wrongly) mancozeb when late blight symptoms have already appeared. ISABU's recommendation is to spray two to three times preventively with mancozeb every 2 weeks from emergence, and at least once curatively with metalaxyl-m when late blight symptoms appear, and a second time a few weeks later if they appear anew. Doses for the applications of both fungicides were 45 g per spray of 15 l which is sufficient to treat 250 m^2. These on-farm trials were carried out with ISABU fertiliser recommendation (NPK 60–90–60) with variety Victoria only as this variety is more susceptible to late blight than the traditional Ndinamagara.

Partial Budgeting (Table 3)

PBA (partial budgeting analysis) is a tool used to assess the costs and benefits associated with a specific change in an individual farm within the production operation (Horton 1982). This tool specifically focuses on the implications of the intended change in a production operation by comparing the benefits and costs resulting from implementing the alternative with respect to the current production practice. Partial budget, like an enterprise budget, is based on a unit (1 potato farm), but it is different from an enterprise budget in the type of costs used. An enterprise budget uses total costs (variable input costs plus fixed input costs) while only variable input costs are used in a partial budget. In a partial budget, income is the gross farm gate benefit. The net benefit is the difference between the gross farm gate benefit and total variable input costs. The following data are required: quantities of inputs which vary between alternative technologies, prices of these variable inputs, yields resulting from the two technologies (the farmer's and the new one) and prices of harvested potatoes. All data are expressed on a per hectare basis. Relevant are the farm gate prices which the farmer pays for inputs or receives for his/her harvest (output). Thus, all input prices included transport costs to the farmer's place. In our case, an alternative technology affects the quality of the harvested potatoes (better quality of seed, and this improves market value of tubers), so different market prices were applied for the different qualities. The same was applicable for the different qualities of inputs utilised (e.g. improved seed costs more than the farmer's seed). In addition to the variable costs of such inputs as pesticides, fertiliser and labour, PBA also accounts for the cost of capital used. The interest rate on capital should be the interest rates that the farmer actually pays for a loan (including service charges and related costs), or the prevailing market rate (the opportunity cost for use of his own capital).

Table 3

Partial budget analysis

Terms used	Acronyms	Formula
Total revenue	TR	Production value (total seed produced × unit price of seed)
Net income	NI	NI = TR − TC
Total costs	TC	FC + VC
Fixed costs	FC	Fixed costs (FC) are those that do not vary between the technologies
Variable costs	VC	VC are those that do vary between the technologies being evaluated
Change in any of the above	Δ	$\Delta NI = \Delta TR - \Delta VC$
Rate of return	RR	$RR = \frac{\Delta NI}{\Delta VC}$
Capital	C	If a farmer buys seed or hires labour, he needs money (capital), and if he uses his own seed or does the work himself, he forgoes income by not selling or not doing

Fixed costs are, by definition, the same for all technologies: $\Delta FC = 0$

Terms used	Acronyms	Formula
		another business activity. Capital is a function of the annual interest rate and the period over which capital is used.
Fixed costs are, by definition, the same for all technologies: ΔFC = 0		

Once the positive and negative effects are identified and quantified, their difference will determine the outcome. If the proposed change has a positive net effect, the change would be considered superior to the current method and would be considered for adoption. If the proposed change has a negative net effect, the change would be considered inferior to the current method and would not be considered for adoption. In the final analysis, it is the difference between the positive and negative effects that determines how the proposed alternative(s) compares with the current method of production.

Results and Discussion

Despite great variation in yield per treatment among growers, sites and seasons, statistically significant results were found and are shown in the following tables.

Table 4 shows that the yields averaged over two growing seasons of the newly introduced variety Mabondo, planted with seed from the research station, were twice that of the traditional variety Ndinamagara, planted with farm-saved seed. This was mainly a result of larger and heavier tubers. The low yield of 6.14 t ha^{-1} for variety Ndinamagara from farm-saved seed is close to the national average. The incidence of brown rot was low with less than 3% of tubers affected.

Table 4

New variety Mabondo with seed from ISABU compared with variety Ndinamagara from farm-saved seed, averaged over seasons 2015A and 2015B ($n = 30$)

Trait	Ndinamagara	Mabondo	LSD 0.05
Yield t ha^{-1}	6.14	12.12	3.914***
% plants harvested	70.1	78.0	8.37^{ns}
Mean tuber weight g	40.1	51.0	10.23*

Trait	Ndinamagara	Mabondo	LSD 0.05
% < 35 mm	54.0	40.7	10.57**
% 35–55 mm	37.5	39.9	9.17^{ns}
% > 55 mm	8.6	19.5	5.64***
% tubers with brown rot	2.2	1.4	1.35^{ns}

Table 5 shows the effect of renewal of seed of variety Ndinamagara on crop yield at 15 farms in the three provinces. Yields were significantly different and almost doubled when the seed was renewed, partly because of fewer missing plants with the new seed (15% compared with 31%). However, the main reason for the yield increase was a doubling of the number of tubers per plant from 5 to 10 (data not shown). The percentage of brown rot-affected tubers was slightly higher (7% compared with 5%) in the crops from farm-saved seed. However, its presence in crops derived from G2 seed indicates that within two generations, probably most tubers are infected with brown rot bacteria and that expression increases with each seed multiplication until it stabilises. The results in Table 5 suggest that most of the yield increase shown in Table 4 can be attributed to the use of new seed rather than to the change of variety.

Table 5

Farm-saved seed of variety Ndinamagara compared with generation 2 seed from ISABU in season 2015B ($n = 15$)

Trait	Farm saved	New G2	LSD 0.05
Yield t ha^{-1}	7.69	13.89	3.051***
% plants harvested	69.3	85.3	12.67*
Mean tuber weight g	42.9	40.7	14.22^{ns}
% tubers with brown rot	7.03	5.10	1.25*

Table 6 shows the effect on yield and incidence of brown rot of an early harvest (80 days), thought appropriate for a seed crop. The results for the two seasons were similar and show that early harvest results in a loss of yield, with more small tubers in both size and weight. However, with relatively low yields of less than 16 t ha^{-1} at maturity, there is little risk of reducing the amount of seed-sized tubers with increasing yields. The incidence of brown rot was variable, but higher in the second season. It was manifest in rotting and oozing tubers or through sticky eye symptoms. The largest increase (21 to 38%) in brown rot from 80 days to maturity was in crops from farm-saved seed of variety Ndinamagara.

Table 6

Crops harvested early at 80 days after planting and harvested at crop maturity: farm-saved (FS) seed of variety Ndinamagara and generation 2 (G2) seed from ISABU of varieties Ndinamagara and Victoria in season 2015A and 2015B (*n* = 15 in both seasons)

Trait	Ndinamagara FS		Ndinamagara G2		Victoria G2		LSD 0.05
	80 days	Maturity	80 days	Maturity	80 days	Maturity	
2015A							
Yield t ha^{-1}			10.15	15.48	9.12	11.84	2.28***
% plants harvested			69.8	62.5	51.3	48.1	7.3***
Mean tuber weight g			26.8	34.2	36.0	57.8	10.1**
% < 35 mm			60.8	44.1	36.0	27.1	8.1**
% 35–55 mm			37.0	32.9	42.0	46.6	9.1^{ns}
% > 55 mm			2.74	8.23	7.77	15.46	3.11***
% tubers brown rot			7.0	17.5	16.0	20.2	9.1^{ns}
2015B							
Yield t ha^{-1}	6.07	9.07	10.01	15.68	8.59	9.46	1.96***
% plants harvested	70.3	68.1	82.0	82.8	70.3	69.9	53.7*
Mean tuber weight g	24.8	27.2	29.9	34.7	29.5	44.7	8.2*

Trait	Ndinamagara FS		Ndinamagara G2		Victoria G2		LSD 0.05
	80 days	Maturity	80 days	Maturity	80 days	Maturity	
% < 35 mm	55.8	37.9	64.0	45.9	39.7	24.6	9.4***
% 35–55 mm	27.2	29.5	33.5	26.8	26.1	50.8	10.0^{ns}
% > 55 mm	3.18	7.47	4.62	10.25	7.40	14.45	5.1***
% tubers brown rot	21.0	37.5	17.8	25.7	39.8	37.4	8.7^{ns}

In the 2015B season, crops from G2 seed of variety Ndimanagara had much higher yields (about 70% higher) than those from farm-saved seed at both harvests, and there were fewer missing plants at harvest. Furthermore, the yield increase between 80 days and maturity was about 50% for crops from both seed sources. The early maturity of variety Victoria is reflected in its much lower yield than variety Ndimanagara at maturity, namely 9.46 compared with 15.68 t ha^{-1} in the 2015B season. It is also reflected in both seasons in its more modest increases in yield between 80 days and maturity. In both seasons, with G2 seed, the proportion of missing plants at harvest was higher for variety Victoria than variety Ndimanagara.

The mid-sized tubers from the 2015B season were stored in diffused light and used for seed in the following 2016A season (Table 7).

Table 7

Crops in season 2016A planted with seed from the previous season (2015B) which had been harvested early at 80 days after planting or at crop maturity from crops planted with farm-saved (FS) seed of variety Ndinamagara and generation 2 (G2) seed from ISABU of the varieties Ndinamagara and Victoria ($n = 15$)

Trait	Ndinamagara FS		Ndinamagara G2		Victoria G2		LSD 0.05
	80 days	Maturity	80 days	Maturity	80 days	Maturity	
Yield t ha^{-1}	11.11	11.07	10.72	11.61	8.28	10.12	1.70*

Trait	Ndinamagara FS		Ndinamagara G2		Victoria G2		LSD 0.05
	80 days	Maturity	80 days	Maturity	80 days	Maturity	
% plants harvested	81.8	77.0	89.0	85.0	73.0	79.3	9.0^{ns}
Mean tuber weight g	65.1	46.3	61.7	52.9	74.8	61.8	10.8*
% tubers brown rot	39.0	11.9	17.8	4.6	15.8	0.8	10.9**

Table 7 shows that the yields of variety Ndinamagara from farm-saved seed and generation 2 seed, also farm saved for one season, were similar at around 11 t ha^{-1}, with the earlier variety Victoria slightly lower yielding. The seed taken from plants harvested at maturity in the previous season systematically yielded crops with smaller tubers (mean tuber weight). With similar yields, this means that the seed harvested at maturity leads to crops with more tubers, probably because they formed more stems per plant.

The results for brown rot are interesting. In the previous crop, brown rot incidence was highest in the late-harvested crops. However, the crops grown from these late-harvested seed tubers had a lower incidence of brown rot. We assume that at the early harvest (Table 6), much brown rot was still latent and came to expression during storage and in the next crop (Table 7). In contrast, the late-harvested crop showed much more brown rot expression, with less still latent, so that healthier seed tubers were selected for the next crop, resulting in the reduction of brown rot. It can be concluded that an early seed harvest does not reduce brown rot disease in the next crop.

Table 8 shows that storage of farm-saved seed in a diffused light, rather than the dark, increased yield (9.15 to 11.76 t ha^{-1}). There was no reduction in mean tuber weight or change in size distribution, so the higher yields were due to a greater number of tubers per plant, probably as a result of reduced top dominance and more stem formation following pre-sprouting in the light (Haverkort et al. 1990). The diffused light also reduced the incidence of brown rot, albeit from an already low level.

Table 8

Variety Ndinamagara crops planted with seed from ISABU, multiplied once by grower and stored in dark and in diffused light store (DLS) ($n = 15$)

Trait	Dark	DLS	LSD 0.05
Yield t ha^{-1}	9.15	11.76	1.43**
% plants harvested	73.5	79.2	15.8^{ns}
Mean tuber weight g	38.2	35.4	18.1^{ns}
% tubers with brown rot	1.93	1.01	0.8*

Table 9 shows the comparison of 30 plots (3 provinces × 5 growers × 2 seasons) which received farmers' fertilisation practice with 30 plots where the recommended 60–90–60 NPK kg ha^{-1} was applied. The latter increased yield by 59%, reduced the percentage of missing plants (from 85 to 70%), increased the proportion of large tubers and reduced the incidence of brown rot.

Table 9

Farmers' fertilisation practice compared with ISABU recommendation of 60–90–60 NPK kg ha^{-1} for variety Ndinamagara crops planted with generation 2 seed from ISABU and grown in 2015A and 2015B ($n = 30$)

Trait	Farmers' practice	NPK 60–90–60	LSD 0.05
Yield t ha^{-1}	9.05	14.4	3.18**
% plants harvested	69.6	84.7	13.3***
Mean tuber weight g	38.8	37.1	14.2^{ns}
% < 35 mm	38.2	40.1	7.6^{ns}
% 35–55 mm	32.0	40.2	5.9**
% > 55 mm	6.01	10.3	3.63*
% tubers with brown rot	25.6	10.2	8.4**

Table 10 shows that the recommended fungicide application (dose, time and type) increased yields by 49% on average, as well as the number of harvested plants and tuber size (mean tuber weight and proportion of large tubers).

Table 10

Control of late blight by fungicide in seasons 2015A and 2015B on variety Victoria crops planted with generation 2 seed from ISABU: farmers' practice of no late blight control compared with ISABU recommendation of blight control with fungicide applications (n = 30)

Trait	Farmers' practice	Fungicide treated	LSD 0.05
Yield t ha^{-1}	6.68	9.94	2.47*
% plants harvested	65.2	77.8	10.3*
Mean tuber weight g	40.1	52.7	7.8**
% < 35 mm	42.8	29.5	11.9*
% 35–55 mm	28.2	42.8	8.1***
% > 55 mm	8.1	16.1	4.8**
% tubers with brown rot	21.6	12.0	11.7^{ns}

Table 11 shows the results of the partial budgeting analysis and comparison of the different tested technologies. It can be seen that the MRRs for new variety Mabondo, new (G2) seed, seed storage in diffused light and the use of fertilisers and fungicides are greater than the acceptable value of 160 so that these changes can be recommended. Furthermore, an early harvest of the farm seed crop is desirable as delaying harvesting to maturity results in an MRR of less than 160. Hence, all of these changes in small-scale farming were profitable and are to be recommended for their potential impacts. Small-scale farming in Burundi represents more than 99% of total farm numbers and manages most of the farmland and other farm assets, despite an agricultural farming policy increasingly dependent on large-scale, high-input farms that specialise in a few crops and concentrated production practices.

Table 11

Partial budgeting analysis and comparison of the different tested technologies: *MRR* margi practice, *NPK* 60–90–60, *CA* chemical application

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	New variety	New seed	Previous farm se

	New variety		**New seed**		**Previous farm se**		
	Ndinamagara	Mabondo	Farm saved	New G2	80 days	Maturity	80 c
					Farm saved		G2
Gross income							
Average yield	6140	12,120	7690	13,890	11,110	11,070	10,7
Price of seed (×1000USD/ton)	0.37	0.75	0.37	0.75	0.37	0.75	0.37
Sale revenue (USD)	2271.8	9090	2845	10,418	4110.7	8302.5	396
Inputs							
Seed rate	1500	2000	1500	2000	1500	2000	150
Seed cost (USD)	555	1500	555	1500	555	1500	555
Fertilisers	0	280	0	280	0	280	0
Fungicides	0	90	0	90	0	45	0
Labour	0	0	0	0	0	0	0
DLS cost							
Capital (seed cost = own seed used + labour)	555	1500	555	1500	370	1500	370
Interest rate for 4 months Cultivation (%)	2	2	2	2	2	2	2
Total variable cost (TVC)	1110	3370	1110	3370	925	3325	925
Net benefit	1161.8	5720	1735	7047.5	3185.7	4977.5	304
Change benefit between farmer practice and improved technology		4558.2		5312.2		1791.8	
Change in TVC between farmer practice and improved technology		2260		2260		2400	
Marginal rate of return (%)		202		235		75	

	New variety	New seed	Previous farm se
MRR > 160	Yes	Yes	No

Concluding Remarks on Potato Production in Burundi

It was shown that yield can be doubled through improved propagation material by introducing healthy seed, especially from a newly selected improved variety. Improved cultural practices such as storage of seed in diffused light, proper late blight control and NPK fertiliser application can also increase yields between 30 and 60% on average, but what are the implications for Burundi?

The highest yield of 47 t ha^{-1} was recorded in a fertilised plot of variety Victoria, treated with fungicide to control late blight (2015A), and grown in the Province Bubanza municipality Musigati on the farm of Mr. Michel Nsananikiye on a fertile soil near the forest. The same grower in the following season recorded a low yield of 1.3 t ha^{-1} in a treatment without late blight control. Despite this large variation, the highest average yield of a treatment was about 15.5 t ha^{-1} in 30 plots of variety Ndimagara planted with G2 seed in the 2015A and 2015B seasons (Table 6). This 'ceiling' is low, especially when compared to neighbouring Rwanda where the national average is almost 15 t ha^{-1} and experimental yields of up to 40 t ha^{-1} have been recorded (Haverkort and Harris 1986). Rwanda has the advantage of fertile volcanic soils whereas the majority in Burundi are feral soils, poor in nutrients and with poor availability of phosphorus for plants. Their relatively poor capacity to hold water compared to volcanic soils, combined with excessive rainfall, risks nitrogen leaching and runoff of fungicides. All of these factors may contribute to the current low maximum average yield in Burundi and hence are worthy of further research and development.

The gain from the use of improved seed of 6 t ha^{-1} at a farm gate price of FB 600 per kilogram is worth a total of FB 3.6 million. Current costs of G2 purchased seed are FB 1500 per kilogram. When planting 2 t ha^{-1}, this works out at FB 3.0 million (G3 would still cost FB 2.5 million), which is hardly economically viable and shows that seed prices need to be lowered considerably. A recently completed new hydroponic minituber production system will move annual production up from 200,000 to 2 million minitubers, and this will reduce the production costs of pre-basic seed. When growers use such seed as a seed stock and apply roguing, the advantages of such seed can be extended over several seasons. Fertiliser costs to apply 60 kg of N, 90 kg of P and 60 kg of K per hectare are FB 420,000, slightly more than the revenue from 1 t of potatoes at farm gate prices. The average gain (Table 9) on 30 plots was 5 t ha^{-1}, so fertiliser application is more profitable than buying pre-basic seed or fungicide application (Table 10).

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