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Least-Cost Seed Potato Production in Ethiopia

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Abstract Improved potato varieties can increase potato yields of smallholders, and thus contribute to food security improvement in Ethiopia. However, the uptake of these varieties by farmers is very limited so far and this is one of the causes of insufficient seed quality in the seed potato system in Ethiopia. The low uptake may be related to the high costs of recommended production methods for these varieties. The objective of this study was to formulate least-cost seed potato production methods for farmers in Ethiopia. The paper used integer linear programming to determine these least-cost seed potato production methods, using published data on the perceived contributions to seed tuber yield and quality of different cultivation and post-harvest management options, and calculated seed potato production cost data for the different options. For the potato-growing districts Jeldu and Welmera, several seed potato production methods were formulated from which farmers can choose an affordable method that will enable them to produce seed potato with reasonable yield and quality levels. Results showed that yield and quality levels could be simultaneously improved at relatively low extra costs, for example, by applying recommended fertilizer rate combined with two fungicide applications. In both districts, most methods were robust to 50% increases in the rental values of land, prices of seed, wage rates, and prices of agrochemicals. Findings can be used by potato development practitioners to advise farmers on the adoption of seed potato technologies that are compatible with their financial resources.

Keywords Ethiopia · Least-cost production · Linear programming · Management attributes · Production method · Seed potato

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Introduction

In Ethiopia, potato (*Solanum tuberosum* L.) can play an important role in improving food security and cash income of smallholder potato growers. Potato production can be increased through increases in acreage and productivity. Currently, only 2% of the potential area in Ethiopia is under potato production and the average productivity of potato is less than 10 Mg/ha. The low productivity is partly due to the use of poor quality seed potatoes of inferior varieties by most potato growers (Mulatu et al. 2005; Gildemacher et al. 2009; Hirpa et al. 2010; International Potato Center 2011). So far, there is no formal institution involved in the production, supply or certification of seed potatoes. Currently, a small amount of good quality seed is supplied by agricultural research institutions, mainly to introduce and demonstrate the impact of improved varieties and cultural practices.

Available improved potato varieties are characterized by high yields and biotic and abiotic stress tolerances. However, the uptake of these varieties by farmers is very limited. The limited uptake is partly a result of limited supply of seed, which in turn is due to the absence of an efficient seed potato system (Gildemacher et al. 2009; Hirpa et al. 2010). Farmers, who adopted improved potato varieties, use suboptimal seed production management practices and produce below their potential (Hirpa et al. 2012). According to Gildemacher et al. (2009), seed potatoes of improved varieties comprised only 1.3% of the total supply of seed potatoes in Ethiopia. In Sub-Saharan Africa (including Ethiopia), there is a high demand for seed potato of improved varieties (Gildemacher et al. 2011). Therefore, supply of a larger amount of quality seed potato (potatoes that comply with seed health, physical, physiological, and genetic quality criteria) of improved varieties is required to increase potato production in the country.

Production and supply of a larger quantity of quality seed potato of improved varieties require an increase in the number of seed potato producers of improved potato varieties. Currently, improved varieties are released to farmers together with an advice for a standard, recommended package of seed potato cultural practices. The low adoption of improved potato varieties and management practices could be caused by high costs related to the adoption of the recommended production method; studies show that new agricultural technologies often require more inputs than existing technologies and farmers are reluctant to adopt them to avoid risk of failure (Yesuf and Bluffstone 2007; Langyintuo and Mungoma 2008; Foster and Rosenzweig 2010; Yu et al. 2011). Reluctance in the uptake of new technologies can be more serious in a situation where markets for credit and insurance are missing (Yesuf and Bluffstone 2007). In Ethiopia, lack of credit is one of the major constraints for adoption of new agricultural technology (Croppenstedt et al. 2003) and a crop insurance market for most crops including potato is missing (Yesuf and Bluffstone 2007; Araya 2011). Therefore, availing least-cost alternative production methods can be one of the means to increase uptake of improved varieties and management practices. Least-cost alternative seed potato production methods could give lower, but acceptable seed potato yield and quality. Subsequently, farmers can decide to invest in the production of seed potato methods with higher seed yield and quality levels than the existing production method. A study of Yesuf and Bluffstone (2007) among Ethiopian farmers showed that the perceived level of risk decreased once the success had convinced farmers that technologies were viable.

The objective of this study was to develop least-cost seed potato production methods for farmers in Ethiopia. The study uses integer linear programming to develop least-cost seed potato production methods. This study uses the results from a previous study (Hirpa et al. 2012) on the perceived contributions to seed potato yield and quality of different levels of the relevant seed potato management attributes (Table 1), and computes the costs of combinations of these seed potato management attribute levels, i.e. of the seed production methods. The empirical application focuses on farmers in the districts Jeldu and Welmera. The results show that yield and quality levels could be simultaneously improved at relatively low extra costs. The knowledge acquired can be used by seed potato production practitioners to advise farmers on the adoption of seed

Table 1 Seed potato production and post-harvest management attributes and their levels

Attribute	Level 1	Level 2	Level 3
Seed source[a]	Own	Market	Institution
Seed size[b]	Small	Medium	Mixed
Storage method[c]	Local	DLS[i]	–
Sprouting method[d]	De-sprouting	Sprouting under special conditions	In-store
Tillage frequency	Three times	Four times	Five times
Planting date[e]	Earlier than recommended period	Within range of recommended period	–
Hoeing and hilling[f]	Hoeing once and small hill	Hoeing twice and small hill	Hoeing twice and big hill
FR[g]	Below recommended rate	Recommended rate	Above recommended rate
FA[h] frequency	One time	Two times	Three times

Source: Hirpa et al. (2012)

[a] Respondents claimed that the three sources differed from each other in quality of seed tuber produced from them

[b] Respondents claimed that the three seed sizes differed from each other in their progeny yield and quality. The farmers defined the medium seed size as equivalent to the size of an egg of a hen of Ethiopian local breed. Tubers smaller than the hen's egg size were classified as small and tubers greater than the hen's egg size were classified as large. The mixed tuber size contained small, medium, and large seed. The experts defined seed size based on tuber diameter: small for 20–35 mm, medium for 36–45 mm and large for >45 mm

[c] Local storage methods included postponed harvesting, bed-like structures located outside the house under a roof and storing tubers loose or in sacks in the residential houses

[d] According to the farmers, the seed potato tubers were usually de-sprouted 2–4 weeks before planting. Sacks, straw or direct sunlight were used to advance sprouting

[e] Farmers planted seed tubers either within the recommended period (June 8–22) or earlier than the recommended period (May 18–June 7)

[f] Farmers assumed hilling to be crucial for high seed yield and that larger hills produced higher tuber yields. There was a large difference in hill size among the farmers in the districts

[g] *FR* fertilizer rate. The recommended application rate (level 2) was 90 kg P_2O_5 ha^{-1} plus 111 kg N ha^{-1}, supplied as 195 kg DAP and 165 kg urea ha^{-1}. Level 1 included an application rate ranging from 25 kg P_2O_5 plus 31 kg N ha^{-1} to less than level 2 and level 3 included an application rate above the recommended rate up to 125 kg P_2O_5 plus 154 kg N ha^{-1}

[h] *FA* fungicide application

[i] *DLS* diffused-light storage

potato technologies that are compatible with their financial resources. The knowledge is also useful for researchers to develop viable alternative production methods in the processes of variety development.

Framework and Model Specification

Consider a farmer producing seed potato using multiple seed potato management attributes. The farmer's technology set (T) is given by:

$$T = \{(p, q) : p\, can\, produce\, q\} \tag{1}$$

where p is a specific combination of levels of seed potato management attributes (or production method) and q is a combination of seed potato yield and quality. A technology set is a list of all technically feasible combinations of inputs (different combinations of levels of seed potato management attributes) and outputs (yield and quality levels measured in terms of relative contributions; Fare and Primont 1995). In this study, feasible combinations of inputs refer to the combinations of levels of seed potato management attributes that enable seed potato producing farmers to produce seed potatoes that satisfy acceptable levels of seed potato yield and quality. To produce seed potatoes, for instance, a farmer can use a combination of levels of seed potato production management attributes denoted as combination (a) that contains levels of seed potato management attributes such as market seed, mixed seed size, local storage, de-sprouting, four times of tillage, earlier than recommended planting date, hoeing twice combined with a small hill size, above recommended fertilizer rate, and two fungicide applications, or a combination of levels of seed potato production management attributes denoted as combination (b) that contains levels of seed potato management attributes such as own seed, small seed size, diffused-light storage, sprouting under special condition, three times of tillage, recommended planting date, hoeing twice combined with a big hill size, recommended fertilizer rate, and three fungicide applications to produce seed potato. Combinations (a) and (b) give different seed potato yields and different levels of seed potato quality. Details on selection of seed potato management attributes and their levels and estimation of the relative contribution of the levels of the seed potato management attributes to seed potato yield and quality are given in the Section Description of Data below.

Linear programming (LP) is a mathematical technique that optimizes a linear function of decision variables (in this case, levels of seed potato management attributes) subject to linear constraints that are expressed as equality, inequality, or bounds in decision variables (Murty 2010). Integer linear programming (ILP) is a special case of LP in which all decision variables are restricted to integer values. This study used ILP to identify least-cost methods of seed potato production that give a minimum level of seed yield and quality. A similar method as in our study was used by Gladwin et al. (2001) to develop multiple livelihood strategies of women farmers in Africa, by Fuglie (2004) to assess least-cost animal rations, by Valeeva et al. (2007) to optimize costs of attaining different levels of chemical and microbial food safety in the dairy chain in The Netherlands, and by Breustedt et al. (2011) to assess how the competitiveness of organic farming is affected by the abolishment of EU milk quota and to investigate to what extent price adjustment might alleviate the effect of these policy changes.

Data on relative contributions of management attribute levels of each management attribute to seed potato yield and quality and costs of an amount of seed potato that could be produced on 0.5 ha were used to develop least-cost combinations (LCC) of levels of the management attributes of seed potato production that give certain levels of seed yield and quality for a given ILP problem specified as

$$\min z = \sum_{a=1}^{A} \sum_{l=1}^{L} C_{al} x_{al} \quad (2)$$

Subject to:

$$\sum_{l=1}^{L} x_{al} = 1, \forall a \in A \quad (3)$$

$$\sum_{a=1}^{A} \sum_{l=1}^{L} r_{alk} x_{al} \geq R_k, \; k = 1, 2 \quad (4)$$

$$x_{al} : \text{binary variable } \forall x_{al}; a = 1, 2 \ldots, A; \; l = 1, 2 \ldots, L \quad (5)$$

where

- z total extra cost of method of production and storage, Ethiopian Birr (ETB) per amount of seed potato that could be produced from 0.5 ha (see the 'Costs of Seed Potato Production' section below)
- A number of seed potato management attributes
- L number of levels within an attribute
- C_{al} extra cost of level l within attribute a, $\forall a \in A$
- x_{al} level l within attribute a, $\forall a \in A$
- r_{alk} increase in yield level (k=1) or quality level (k=2) achieved due to selection of attribute-level l within attribute a, $\forall a \in A$
- R_k required yield level (k=1) or quality level (k=2)

Description of Data

Two types of data were used: (1) perceived relative contributions of levels of seed potato management attributes to yield and quality, and (2) costs.

Relative contributions of levels of seed potato management attributes to yield and quality

Data on relative contributions of levels of seed potato management attributes to seed potato yield and quality were adopted from Hirpa et al. (2012). In Ethiopia, there was no defined standard for seed potato quality. Therefore, quality was composed of three seed potato quality variables as defined by respondents that participated in the study by

Hirpa et al. (2012) i.e. (1) proportion of medium tuber size in total produce (the higher the proportion of medium sized tubers, the higher the quality); (2) disease pressure (the lower the infestation of potato plants by late blight, bacterial wilt, and other diseases, the higher the quality); and (3) physical damage (the lower the proportion of bruised and cracked tubers, the higher the quality). The relative contribution of the levels of the management attributes to seed potato yield and quality was estimated by conducting two consecutive studies: a Delphi study and a conjoint analysis.

Selection of Seed Potato Management Attributes and their Levels The Delphi study was conducted in two major seed potato growing districts, Jeldu and Welmera, in Ethiopia, to identify management attributes and their levels and to prioritize them based on their contribution to seed yield and quality. The Delphi technique is a survey method that looks for the most reliable consensus among a group of experts by means of questionnaires in different rounds (Linstone and Turoff 1975). The Delphi study was undertaken in September 2010 with five experts (three agronomist-breeders and two agricultural extension specialists from Holetta Agricultural Research Centre, located in Welmera) and 20 farmers (10 from each district). Experts were selected based on their experience (>10 years) in potato research and on-farm demonstrations. The farmers were selected from each of the two districts based on their experience (8–10 years) in seed potato production. The authors believe that the experience of a respondent is directly related to the level of expertise of the respondent. Besides, the sample farmers were members of seed producers' cooperatives and had received training on seed potato production and post-harvest management from the experts of Holetta Agricultural Research Centre. Quality of results of Delphi studies depends on the level of appropriate expertise of the respondent. A literature study by Rowe and Wright (1999) shows that the number of respondents ranges from 3 to 98.

The Delphi survey was undertaken in two evaluation rounds. In the first round, farmers and experts were provided with a list of seed potato management attributes individually, and were asked to make any amendment to the initial list if needed. The initial list of seed potato management attributes was based on literature review and the authors' experience. The experts and farmers were asked to rate the management attributes with respect to their perceived importance for yield and quality separately by dividing 100 points among the management attributes, and then to give an explanation for the scores given. In Jeldu, farmers added grading and type of seed potato transport to the list of management attributes and removed negative selection and haulm destruction from the list. In Welmera, farmers added grading to the list for quality evaluation. The experts removed rotation and variety from the list for quality evaluation but did not make any amendment to the list for the yield evaluation.

The management attributes considered most relevant were: seed source, seed size, storage method, sprouting methods, tillage frequency, planting date, hoeing frequency combined with hill size, and the combination of fertilizer rate and fungicide application frequency. Table 1 presents the seed potato management attributes and their levels. For further details on the Delphi study, see Hirpa et al. (2012).

Estimation of the Relative Contributions of Seed Potato Management Attribute Levels to Seed Potato Yield and Quality After the Delphi study, the relative effects of the selected management attributes on seed yield and quality were quantified by a conjoint analysis. Conjoint analysis is a technique that is widely used in marketing to measure contributions of different product attributes (e.g. flavour versus size) to the overall preference of a product (e.g. apple; Green and Rao 1971; Hair et al. 2006; Rao 2008).

This study used the opinions of 324 seed potato farmers from the two major seed potato growing districts, Jeldu and Welmera. The farmers were randomly selected from seed potato growers from the two districts, 162 farmers in each district. The sample size comprised about 40% of the total number of seed potato growers in Jeldu and Welmera. The questionnaire was pre-tested with 10 respondents, five from each district, to check for the question content and question order in the first part and to decide on the best way to present the conjoint task. The seed producers were farmers who were members of seed potato producers' cooperatives and produced seed potato under the supervision of experts from Holetta Agricultural Research Centre. The seed growers had received training on seed potato production and post-harvest management from experts from Holetta Agricultural Research Centre.

The data were collected through face-to-face interviews using a 0–10-scale (Juster 1966), mean-centred (to eliminate different use of scale by the respondents (Endrizzi et al. 2011)) and analysed using factorial ANOVA, in which the management attributes were included as factors. In this study, for evaluation of yield 0 means 'I cannot produce seed potato by using this combination of attribute levels' and 10 is 'I can produce seed potato at the maximum attainable yield level by using this combination of attribute levels'. The anticipated maximum yield was used as the reference value to evaluate the profiles for yield because there was no one common actual maximum yield value to be considered as a reference. That is why anticipated maximum yield was considered as proxy for the actual maximum yield. The same scale was also used to evaluate the combinations of management attributes for quality in which 0 had the meaning 'I cannot produce seed potato by using this combination of attribute levels' and 10 was 'I can produce seed potato at the maximum attainable quality by using this combination of attribute levels'.

According to Hirpa et al. (2012), the results of the conjoint analyses were considered robust as the results obtained from the model were comparable to the results of the Delphi study and from a social sciences perspective, the adjusted R^2 values were relatively large for both yield (0.266) and quality (0.296). Details can be found in Hirpa et al. (2012).

The contributions have artificial units that indicate the relative effect of levels of seed potato management attributes on seed yield and quality. The higher the value of the contribution, the higher the positive effect the management attribute level has on seed yield or quality. From this point onwards, the units of the contributions are referred to as 'points'. Each contribution within a seed management attribute can be interpreted as the relative effect of that particular attribute level, in terms of points, on seed yield and quality when that level is selected.

Table 2 presents the relative contributions (for yield in columns 2 and 5 and for quality in columns 3 and 6). The sum of the relative contributions for levels of management attributes that compose a certain production method represents the total effect of this production method on the improvement of seed potato yield and quality, relative to the production method with the minimum yield or quality level. From here, a method of seed potato production is referred to as a plan. The maximum yield or quality level refers to the plan in which for each seed potato management attribute the level with the highest relative contribution was selected. The sum of the highest relative contributions at each management attribute shows the maximum yield or quality levels achievable in this study. The highest sums of relative contributions were 5.96 for yield and 6.00 for quality in Jeldu and 5.50 for yield and 5.45 for quality in Welmera.

Costs of Seed Potato Production

Partial budgeting (Huirne and Dijkhuizen 1997) was used to calculate extra costs resulting from the change in attribute level within a seed potato management attribute, relative to the attribute level representing the lowest cost (Table 2, columns 4 and 7). The extra costs were computed for an amount of seed potato that could be produced on 0.5 ha of land. In the 2010 growing season, many farmers (43.8% in Jeldu and 28.4% in Welmera) used 0.5 ha to produce seed potato. Costs were calculated for each seed potato management attribute level based on the data given in the Appendix in Tables 3, 4, and 5. Data on farm gate price of seed potato, rental value of land, proportion of tubers appropriate for seed from total tubers harvested, seed rates, fertilizer rate, and anticipated maximum yield were collected from a sample of 324 randomly selected seed growers from two districts, Jeldu and Welmera. Data on amount of human and ox labour, seed potato yield, average prices of market seeds over 5 years, and proportion of seed sizes when a given seed size was planted were collected from 20 farmers, 10 from each district, who had recorded at least some of the inputs used in seed potato production. The sample farmers were among the 324 farmers and the data were from their records and memories. These farmers had 8–10 years experience in seed potato production and had a formal education level of grade 6–10. Data on wage rates (for hoeing and harvesting, ox with operator, and fungicide application), cost to transport seed from storage places to farms and produce from farms to storage places, prices of fertilizers and fungicide, and payments made on contract basis for de-sprouting, sprouting under special condition, guarding, and grading and store loading, were obtained from the sample farmers. Details of the cost calculation and the assumptions made are given below for each attribute level.

Seed Source and Size Own seed is seed produced by a farmer in the previous production cycle for own use in the next cycle. Costs of land, seed, labour, fertilizers, fungicide, transportations, and storage; and amount of yield that could be produced when a particular seed size was planted were used to calculate costs of production of own-small, own-medium, and own-mixed seed potatoes (Appendix Table 4). To complete the cost computation of own seeds, two assumptions were made: (1) previous own seed was used to produce the own seed under consideration and (2) diffused-light storage (DLS) with a capacity of 10 to 12 Mg was used to store the seeds.

Market seed is seed potato obtained from nearby open markets. Prices for market seed were obtained from farmers (Appendix Table 3). Only purchase costs were

Table 2 Relative contribution to yield and quality and extra costs of different levels of seed potato management attributes in two districts

Attributes	Jeldu			Welmera		
	Yield (in points)[a]	Quality (in points)[a]	Extra costs (ETB/ 0.5 ha)	Yield (in points)[a]	Quality (in points)[a]	Extra costs (ETB/ 0.5 ha)
Seed source and size						
Own-small	0.23	0.30	330	0.62	0.65	0
Own-mixed	0.19	0.36	751	0.56	0.63	623
Own-medium	0.60	0.80	208	0.71	0.86	143
Market-small	0.04	0.00	0	0.06	0.02	25
Market-mixed	0.00	0.06	1,010	0.00	0.00	1,390
Market-medium	0.41	0.50	950	0.15	0.23	1,050
Institution-small	0.43	0.49	850	0.54	0.81	925
Institution-mixed	0.39	0.54	3,025	0.48	0.80	2,690
Institution-medium	0.80	0.99	3,110	0.63	1.02	2,810
Storage method						
Local	0.00	0.00	0	0.00	0.00	0
DLS[b]	0.91	1.02	16,000	0.78	0.82	16,000
Sprouting method						
De-sprouted	0.00	0.00	14.4	0.00	0.02	15
Special action	0.10	0.01	144	0.12	0.00	170
In store	0.51	0.56	0	0.45	0.49	0
Tillage frequency						
Three	0.16	0.00	0	0.00	0.00	0
Four	0.00	0.41	105	0.19	0.20	175
Five	0.15	0.30	210	0.11	0.27	350
Planting date						
Earlier	0.00	0.00	0	0.00	0.00	0
Recommended	0.61	0.59	1,010	0.28	0.20	1,099
Hoeing frequency and hill size						
Once and small	0.12	0.00	0	0.06	0.00	0
Twice and small	0.00	0.23	280	0.00	0.22	310
Twice and big	0.86	0.87	380	0.92	0.86	464
Interaction between FR[c] and FA[d]						
Below recommended FR and once FA	0.00	0.36	0	0.00	0.00	0
Below recommended FR and twice FA	0.25	0.00	655	0.63	0.17	660
Below recommended FR and thrice FA	0.43	0.38	1,310	0.92	0.65	1,320
Recommended FR and once FA	0.62	0.46	902	0.93	0.66	894

Table 2 (continued)

Attributes	Jeldu			Welmera		
	Yield (in points)[a]	Quality (in points)[a]	Extra costs (ETB/ 0.5 ha)	Yield (in points)[a]	Quality (in points)[a]	Extra costs (ETB/ 0.5 ha)
Recommended FR and twice FA	2.11	1.56	1,557	2.17	1.79	1,554
Recommended FR and thrice FA	1.50	1.25	2,212	2.08	1.62	2,214
Above recommended FR and once FA	0.36	0.24	1,214	0.92	0.47	1,189
Above recommended FR and twice FA	0.70	0.67	1,869	1.34	1.25	1,849
Above recommended FR and thrice FA	1.08	1.09	2,524	1.34	1.39	2,509

Extra costs are calculated for seed tubers produced on 0.5 ha

[a] Adopted from Hirpa et al. (2012)

[b] DLS represents diffused-light storage

[c] FR represents fertilizer rate

[d] FA represents fungicide application

considered. Storage costs were not included because farmers usually buy seed potatoes a few days before planting.

Institution seed is seed potato produced and supplied by a formal institution. Holetta Agricultural Research Centre was the only formal institution that supplied seed potato to farmers in the two districts. The research centre supplied a small amount of seed potato free of charge to demonstrate and popularize improved potato varieties. Therefore, there were no actual prices for institutional seed potato and prices of seed potato obtained from specialized seed potato growers were used as proxies for institution-seed potato prices (Appendix Table 3).

Storage Method Seed potatoes are stored using traditional local storage methods or DLS. Local seed potato storage methods include bed-like structures situated under a roof outside or inside a residential house, residential house, and postponed harvesting. For the sake of simplicity, all local storage methods were assumed to have the same storage characteristics and their costs were set at zero. For DLS, it was assumed that additional costs for construction had to be made. In both districts, DLSs varied in their sizes and economic lives. During field observations made in 2011, DLSs were found to vary in size from 12–160 m^2 and in economic life from 5 to 20 years. Overload was one of the reasons for the short economic lives of some of the DLSs. Farmers loaded 0.12 to 0.20 Mg seed potato per square metre against a recommended load of 0.10 Mg seed potato per square metre shelf space. A DLS of average economic life of 10 years that has a size of 30 m^2 floor space was used to estimate cost of storage. This is an ideal size of DLS with a storage capacity of 10 to 12 Mg seed potato. The costs of construction for an average DLS were approximately the same in both districts; they were estimated to be 16,000 ETB.

Sprouting Method Seed potato sprouting methods are in-store sprouting, de-sprouting and sprouting under special condition. In-store sprouting is leaving seed potato to sprout where it is stored. The cost of the in-store sprouting method was set at zero. De-sprouting was practised to remove apical dominance. Cost of de-sprouting was wage paid for labour to de-sprout 1.2 Mg of seed potato in Jeldu and 1 Mg in Welmera. Sprouting under special conditions is a method used to advance sprouting. In the studied areas, farmers used storage in straw, sacks, and sun to advance sprouting. In the cost estimation of sprouting under special condition, only cost of labour was considered.

Tillage Frequency, Planting Date, and Hoeing/Hill Size Costs for land tillage frequency were calculated per 0.5 ha. The costs included ox labour and operator. The data on number of ox days per tillage and wage rates are given in Appendix Table 3. Costs differed between the two planting dates (earlier than recommended period and recommended period) because of difference in labour efficiency. Labour efficiency in the earlier than recommended planting period was higher than in the recommended planting period because of lower workability of soil and interruption of agricultural activities due to rainfall in the latter. Because of high rainfall, hoeing and hill making are slower in the recommended period compared with the earlier than recommended period. According to key informants, in Jeldu and Welmera, amounts of labour used for hoeing and hilling of seed potato fields planted earlier than the recommended period were lower by 50% than the amount of labour required for the same size of seed potato field planted in the recommended period. Fungicide application frequency was found to increase by one application for potato planting in the recommended period compared with potato planted earlier than the recommended period because of higher incidence of late blight (caused by *Phytophthora infestans*) on the former.

Costs of hoeing frequency and hill size were estimated based on the amount of labour required for hoeing and hilling (Appendix Table 3). Further assumptions were made to estimate costs of the two types of hill size. The labour required to make big hills was assumed to be two times that of the labour required to make small hills. The average number of labour days required for first hoeing, and second hoeing combined with hilling is given in Appendix Table 3.

Fertilizer and Fungicide Costs of fertilizer rate (FR) and fungicide application (FA) comprised prices of fertilizers (DAP and urea) and fungicide at a nearby store and costs of labour to apply fertilizers and fungicide on the potato field. Data on the amount of fertilizer for the three rates (below recommended, recommended, and above recommended), FA frequency, amount of fungicide per application, prices of fertilizers, price of fungicide, and the costs of labour to apply fertilizers and fungicide are presented in Appendix Table 5.

Data Analysis

The ILP model was specified in a Microsoft Excel spread sheet and solved using solver with integer tolerance of 0% to develop optimal seed potato production and post-harvest management plans. The optimal plans were developed for two scenarios, representing two situations. The first scenario comprised optimal plans developed for farmers who wanted to start seed potato production or develop a new plan of seed production. The second scenario developed optimal plans for farmers using DLS. Most seed potato growers use DLS to store seed potatoes of improved varieties (Hirpa et al. 2012).

In the first scenario, the first optimal plan was developed by relaxing the constraint on yield and quality levels (inequality constraint (4)). The second and subsequent plans were developed by imposing inequality constraint (4). Yield and quality for each subsequent optimization were set to be greater than or equal to the yield and quality levels of the preceding optimal plan plus 0.001 points to force the model to generate a next optimal plan rather than to repeat a plan. The process continued until the model stopped generating a new optimal plan. The second scenario used the same constraints and processes as the first scenario but included a constraint that forced DLS to be included in the optimal plans.

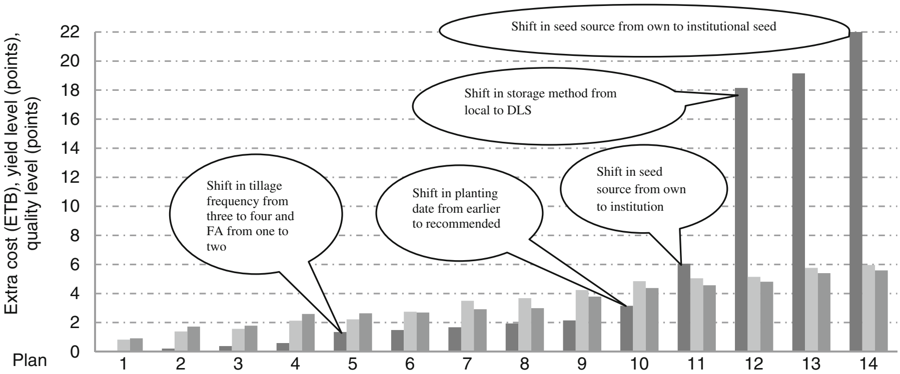
For each plan, sensitivity analyses were conducted at 25% and 50% increases in rental value of land, prices of seed potatoes (seed potatoes used to produce own small, own mixed, and own medium size seed potatoes), wage rates of human and oxen labours, and agrochemicals (fertilizers and fungicide).

Results

This section presents results of least-cost seed potato production plans under two scenarios.

Scenario I

Figures 1 and 2 present minimum total extra costs of plans of seed potato production to achieve certain seed yield and quality levels in Jeldu and in Welmera, respectively. In this scenario, 14 plans in Jeldu and 19 plans in Welmera were generated before the model stopped giving an optimal plan. Minimum total extra costs increased gradually with the gradual increases in seed yield levels and seed quality levels for Plans 1 through 11 in Jeldu and 1 through 15 in Welmera. For plans 12 through 14 in Jeldu and 16 through 19 in Welmera, the costs increased abruptly. The abrupt increase in the costs in both districts was caused by the inclusion of DLS in the plans (Figure 1 for Jeldu and Figure 2 for Welmera). Plans 7 to 11 in Jeldu and 10 to 15 in Welmera gave near to average and above average of their respective districts yield and

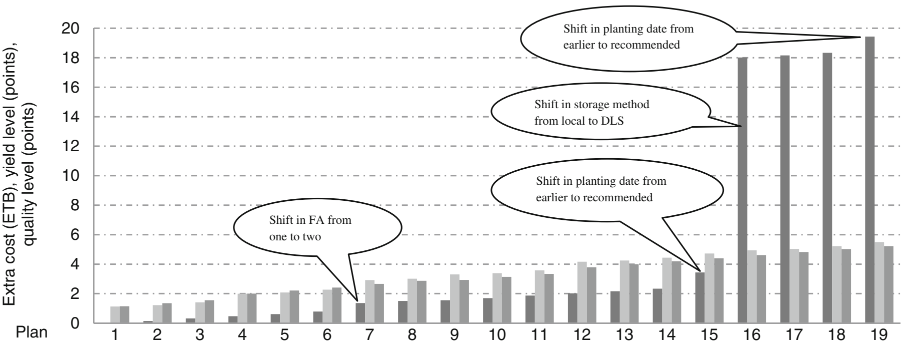


Plan	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Extra cost	0.00	0.21	0.38	0.59	1.35	1.49	1.68	1.94	2.15	3.16	6.06	18.15	19.16	22.06
Yield	0.83	1.39	1.57	2.13	2.22	2.75	3.50	3.68	4.24	4.85	5.05	5.15	5.76	5.96
Quality	0.92	1.72	1.79	2.59	2.64	2.69	2.92	2.99	3.79	4.38	4.57	4.81	5.40	5.59

Fig. 1 Minimum total extra costs of plans of seed potato production to achieve certain yield and quality levels of seed potato in Jeldu. *FA* fungicide application frequency, *DLS* diffused-light storage

quality levels at low extra costs (less than ETB 6,100 per 0.5 ha in Jeldu and less than ETB 3500 per 0.5 ha in Welmera).

In this scenario, all plans were robust to a 50% increase in rental value of land in both districts and wage rates (human and bullock labours) in Jeldu. In Jeldu, all plans except plans 2 and 7 were robust to 50% increase in prices of seed potatoes (seed potatoes used to own small, own mixed and own medium). In Welmera, more than 60% of the plans were robust to a 50% increase in prices of seed potatoes (only plans 2, 5, 8, 10, 13, and 17 changed at a 25% increase and plans 3 and 11 changed at 50% increase). In Welmera, 25%



Plan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Extra cost	0.00	0.14	0.32	0.46	0.61	0.78	1.36	1.50	1.55	1.70	1.87	2.02	2.16	2.34	3.44	18.02	18.16	18.34	19.44
Yield	1.13	1.22	1.41	1.99	2.08	2.27	2.92	3.01	3.30	3.39	3.58	4.16	4.25	4.44	4.72	4.94	5.03	5.22	5.50
Quality	1.14	1.35	1.55	2.00	2.21	2.41	2.66	2.87	2.93	3.14	3.34	3.79	4.00	4.20	4.40	4.61	4.82	5.02	5.22

Fig. 2 Minimum total extra costs of plans of seed potato production to achieve certain yield and quality levels of seed potato in Welmera. *FA* fungicide application frequency, *DLS* diffused-light storage

increase in wage rates changed plan 8 and a further increase in wage rates changed one more plan, plan 7. Of total plans 65% in Jeldu and 74% in Welmera were robust to a 50% increase in the prices of agrochemicals (fertilizers and fungicide).

Scenario II

Figures 3 and 4 present minimum total extra costs required to achieve certain yield and quality levels of seed potato when DLS was included in all plans in Jeldu and Welmera, respectively. In this scenario 11 plans in Jeldu and 15 plans in Welmera were generated. In both districts, minimum total extra costs increased gradually across plans with the gradual increases in yield and quality levels (Fig. 3 for Jeldu and Fig. 4 for Welmera).

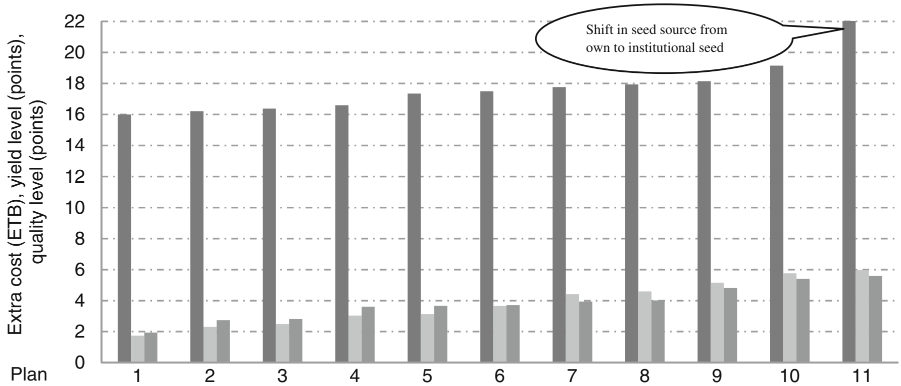
Like in Scenario I, all plans were robust to a 50% increase in rental value of land in both districts and wage rates in Jeldu. Of total plans, about 82% in Jeldu and about 54% in Welmera were robust to a 50% increase in prices seed potatoes. In Welmera, 87% of the plans were robust to a 50% increase in wage rates. A 25% increase in the price of agrochemicals did not change 83% of the plans in Jeldu and 99% of the plans in Welmera but a further increase in the price to 50 left 55% of the plans in Jeldu and 60% in Welmera unchanged.

Discussion

This study used an integer linear programming model that employs the perceived impacts of levels of management attributes to yield and quality to determine least-cost seed potato production plans. The results showed that, in both districts, alternative plans could be developed from which farmers can select based on the amount of money they can allocate to seed potato production.

In the first scenario, there were 14 cost effective plans in Jeldu and 19 in Welmera. Among these plans, some had low costs (e.g. plans 9 to 11 in Jeldu and plans 12 to 15 in Welmera) but gave yield and quality levels comparable with high cost plans (plans with DLS) suggesting a potential for improving yield and quality levels with local storage methods. These least-cost plans, except plan 13 in Welmera, were robust to a 50% increase in the rental value of land, prices of seed potatoes, wage rates, and prices of agrochemicals.

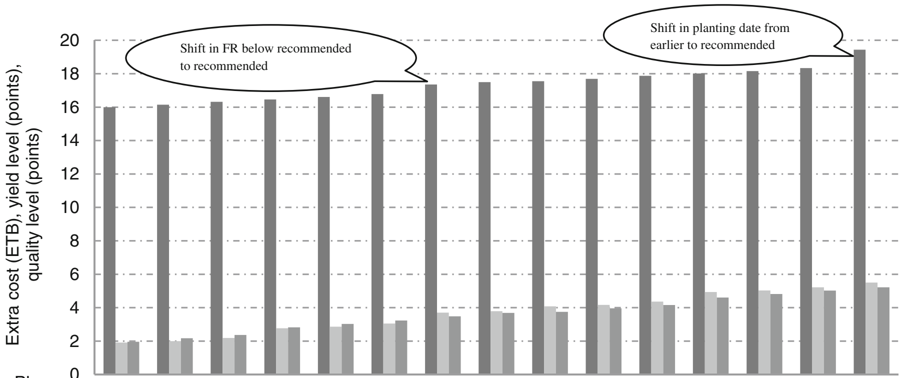
In both districts, the majority of plans in the first scenario contained own medium sized seed, local storage method, in-store sprouting method, three times of tillage, earlier than recommended planting date, hoeing twice combined with big hill size, and recommended FR combined with two FAs. However, there were some differences between the plans in the two districts. Some plans in Jeldu but none in Welmera contained small-sized market seed indicating that market seed was more important for farmers in Jeldu than in Welmera. This result supports the finding of Hirpa et al. (2012) that revealed a low trust in market seed by farmers in both districts because of diseases. They also found



Plan	1	2	3	4	5	6	7	8	9	10	11
Extra cost	16.00	16.21	16.38	16.59	17.35	17.49	17.77	17.94	18.15	19.16	22.06
yield	1.74	2.30	2.48	3.04	3.13	3.66	4.41	4.59	5.15	5.76	5.96
quality	1.94	2.74	2.81	3.61	3.66	3.71	3.94	4.01	4.81	5.40	5.59

Fig. 3 Minimum total extra costs of plans of seed potato production to achieve certain yield and quality levels of seed potato when DLS is included in all plans in Jeldu

that the extent of miss-trust was higher in Welmera than in Jeldu which was attributed to the prevalence of bacterial wilt in Welmera (no bacterial wilt in Jeldu). A larger number of plans in Welmera than in Jeldu contained four times tillage and hoeing once combined with small hill size, indicating farmers in Welmera gave higher emphasis to tillage and less emphasis to hoeing than farmers in Jeldu.



Plan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Extra cost	16.00	16.14	16.32	16.46	16.61	16.78	17.36	17.50	17.55	17.70	17.87	18.02	18.16	18.34	19.44
Yield	1.91	2.00	2.19	2.77	2.86	3.05	3.70	3.79	4.08	4.17	4.36	4.94	5.03	5.22	5.50
Quality	1.96	2.17	2.37	2.82	3.03	3.23	3.48	3.69	3.75	3.96	4.16	4.61	4.82	5.02	5.22

Fig. 4 Minimum total extra costs of plans of seed potato production to achieve certain yield and quality levels of seed potato when DLS is included in all plans in Welmera. *FA* fungicide application frequency

In the second scenario, most of the plans (plans 1 through 8 in Jeldu and plans 1 through 11 in Welmera) required higher costs than plans with roughly similar yield and quality levels in the first scenario, indicating that the inclusion of the DLS in the plans contributed more to the rise of costs than to the improvement in yield and quality levels. In this scenario, plans that comprised levels of management attributes such as recommended FR combined with two FAs and twice hoeing combined with big hills (e.g. plans 9 through 12 in Jeldu and plans 12 through 15 in Welmera) gave high yield and quality levels, indicating a seed potato grower who had DLS had to use high levels of other management attributes to reap a maximum benefit from seed potato production. In both districts, most plans included own medium-sized seed, three times of tillage, earlier than recommended period, hoeing twice combined with big hill size, and recommended FR combined with two FAs. In Jeldu, some plans comprised market seed and institutional seed but in Welmera, all plans comprised own seed indicating the difference in the importance of seed source between the districts.

According to our results, seed potato growers were highly heterogeneous in plans they followed to produce seed potato in 2010. Plans (one for Jeldu and one for Welmera) developed by using levels of management attributes used by the majority of seed potato growers to produce seed in 2010 were followed only by 9.9% in Jeldu and 13.0% in Welmera. These plans were not similar to any of the plans developed through optimization. The levels of seed potato management attributes used by the majority of the farmers were own medium-sized seed (75.9% in Jeldu and 74.7% in Welmera), DLS (81.5% in Jeldu and 71.6% in Welmera), in-store sprouting (100% in both districts), four times of tillage (70.4% in Jeldu and 66.0% in Welmera), planting earlier than recommended period in Jeldu (81.5%), planting within the recommended time range in Welmera (60.5%), hoeing twice combined with big hill size (59.3% in Jeldu and 80.9% in Welmera), and below recommended FR combined with two FAs (48.8% in Jeldu and 56.2% in Welmera). By advising farmers to adopt plans that are affordable to them, it is possible to classify farmers into groups based on the plans they use, and provide demand driven supports. The supports could be technical advises and inputs supply.

The plans developed in this study were based on relative contributions of levels of selected seed potato management attributes to seed yield and quality and minimum extra costs required to shift to other levels of seed potato management attributes. The change in the plans could be caused by changes in the extra costs. The amount of extra costs is affected by changes in the rental values of land, prices of seed potatoes, wage rates and prices of agrochemicals. For instance, the price of DAP increased by about 25% between 2010 and 2011. The result of the sensitivity analysis showed that most plans were robust to 25 and 50% increases of rental values of land, prices of seed potatoes, wage rates and prices of agrochemicals in all scenarios and in both districts.

This study was conducted in two major seed potato growing areas of Ethiopia and thus the results may not be used in their exact form to other seed potato growing areas in Ethiopia. The relative contributions of management attributes to seed yield and quality are based on perception data collected from seed growers. These results have to be supported by field experiments. Besides, a follow-up research is important to analyse the profitability of the plans and also to verify acceptability of the plans by seed growers.

Conclusions

This paper developed least-cost plans for seed potato production in two regions in Ethiopia, i.e. Jeldu and Welmera. The plans were developed for two scenarios representing different situations for farmers. In the first scenario representing farmers that start seed potato production or develop a new plan for seed production (scenario I), 10 plans (out of 14) in Jeldu and 14 plans (out of 19) in Welmera required relatively low extra costs (less than 28% of the plan with the highest extra cost in Jeldu, i.e. plan 14, and less than 18% of the plan with the highest extra cost in Welmera, i.e. plan 19) but gave substantially higher seed potato yield levels (84.7% of the plan with the highest yield level, in Jeldu and 85.8% of the plan with the highest yield level in Welmera) and quality levels (81.7% of the plan with the highest quality level in Jeldu and 84.3% of the plan with the highest quality level in Welmera. Therefore, in Jeldu and Welmera, seed potato growers could improve seed yield and quality levels compared with default levels by adopting an affordable plan. These least-cost optimal plans can also attract non-adopters to adopt improved potato varieties, and production and post-harvest management practices.

Results of the scenario representing farmers using DLS (scenario II) showed that seed potato growers could improve seed potato yield and quality levels by applying levels of seed potato management attributes with higher yield and quality contributions (for example, use of recommended fertilizer rate combined with two fungicide applications) than those with lower yield and quality contributions (for example, use of below recommended fertilizer rate combined with two fungicide applications).

The results of this study can be used by extension service officers to recommend farmers a plan that they deem affordable and that enables farmers to achieve acceptable yield and quality levels. In both districts, farmers currently use a wide variety of plans to produce seed potato. This situation could be an obstacle to designing and delivering advices that can help farmers to improve seed potato production. The plans developed in this study can help experts to categorize farmers into different groups based on the plans they prefer to follow and give advice to farmer groups rather than farmers individually. For researchers, the knowledge is useful to develop viable alternative plans of seed potato. The model can be used by policy makers as a tool to steer cost-effective food security improvements in Ethiopia.

Appendix

Table 3 Mean values of seed potato prices, rent, proportion of seed, seed rates, amount of labour and cost of labour in two districts

Item	Jeldu			Welmera		
	n	Mean	Std. dev.	*n*	Mean	Std. dev.
Price (ETB[a]/Mg[b]) of medium size seed potato	130	3,211	1,041.5	141	3,723	936.1
Land rent (ETB/ha)	81	2,019.0	1,131.5	88	1,430.5	835.8
% seed potato from total tubers harvested from seed potato plot	147	70.0	18	155	78.6	15
Seed rate when planting small seed size (Mg/ha)	54	1.7	0.61	83	1.5	0.57
Seed rate when planting medium seed size (Mg/ha)	55	2.4	0.97	84	2.0	0.72
Seed rate when planting mixed seed size (Mg/ha)	54	3.1	1.20	82	2.6	0.94
Below recommended DAP rate (kg/ha)	85	101.6	37.72	112	96.2	40.0
Recommended DAP rate (kg/ha)	3	195	0	1	195	0
Above recommended DAP rate (kg/ha)	74	215.2	40.29	49	222.5	45.12
Below recommended urea rate (kg/ha)	140	73.5	38.35	134	82.0	37.41
Recommended urea rate (kg/ha)	3	165	0	1	165	0
Above recommended urea rate (kg/ha)	19	211.4	34.27	27	199.0	22.29
Bullock and operator labour required to plough 1 ha and lift tubers produced on 1 ha (ox days (OD)[c])						
1st tillage	10	7.2	1.03	10	7.0	1.83
2nd tillage	10	5.3	0.48	10	6.2	2.10
3rd tillage	10	4.9	0.57	10	5.3	1.70
4th tillage	10	4.6	0.63	10	5.0	1.15
Lifting tubers	10	9.0	1.05	10	9.1	1.10
Human labour (in man-day (MD)[d]) required for 1 ha						
Planting	10	22.0	3.90	10	17.9	2.60
1st hoeing	10	28.0	4.90	10	24.8	1.40
2nd hoeing plus hilling[e]	10	48.0	5.10	10	49.5	7.20
Harvesting	10	42.4	4.80	10	45.2	5.67
Grading (sorting) and store loading of 1 Mg tubers	10	2.0	0.47	10	1.5	0.33
Anticipated maximum yield (Mg/ha)	162	33.3	9.3	162	25.3	9.6
Yield (Mg/ha) of progeny of small size seed	10	16	1.23	10	18	1.08
Yield (Mg/ha) of progeny of medium-size seed	10	35	3.02	10	27	2.30
Yield (Mg/ha) of progeny of mixed size seed	10	27	1.89	10	22	1.70

Table 3 (continued)

Item	Jeldu			Welmera		
	n	Mean	Std. dev.	*n*	Mean	Std. dev.
Prices[f] of 1 Mg market seed of different sizes						
Small seed size	10	1,000	233.33	10	1,300	163.30
Medium seed size	10	1,500	313.30	10	2,000	266.67
Mixed seed size	10	1,200	253.33	10	1,800	230.94
Prices of 1 Mg of improved seed of different sizes						
Small seed size	10	2,000	356.34	10	2,500	278.89
Medium seed size	10	3,300	924.42	10	3,760	620.39
Mixed seed size	10	2,500	444.36	10	2,800	301.84
Price of 1 Mg tubers (unfit for seed) sold as ware potato	10	800	105.41	10	1,000	124.72
Cost of labour (ETB) for de-sprouting 1 Mg seed	10	12	2.05	10	15	2.36
Cost of labour (ETB) for sprouting under special conditions 1 Mg seed	10	120	14.91	10	170	18.86
Cost of transportation of 100 kg seed from home to the field	–	6	–	–	3	–
Ox day (wage) rate	–	50	–	–	70	–
Wage rate (1 MD)	–	20	–	–	25	–
Cost fungicide application (1 MD)	–	50	–	–	60	–
Price of 100 kg fertilizer—DAP	–	1,055	–	–	1,052	–
Price of 100 kg fertilizer—urea	–	888	–	–	886	–
Price of 1 kg fungicide (Ridomil MZ 63.5% WP)	–	420	–	–	420	–
Cost of transportation of 100 kg tubers from field to home	–	7	–	–	3	–
Guarding potato plant and tubers on the field (1 ha for 1 month)	–	400	–	–	400	–

Table 4 Cost[a] (in ETB[b]) required to produce and store own seed that could be produced on 0.5 ha in two districts

Item	Jeldu			Welmera		
	Quantity	Unit cost	Total cost	Quantity	Unit cost	Total cost
A. Own small-sized seed potato						
1. Rental value of land	0.5 ha	2,019	1,010	0.5 ha	1,431	716
2. Seed (seed at 1.7 Mg[c]/ha in Jeldu and 1.5 Mg/ha in Welmera) for 0.5 ha	0.85 Mg	2,000	1,700	0.75 Mg	2,500	1,875
3. Cost of 1 Mg of seed transportation to the field (ETB)	0.85 Mg	60	51	0.75 Mg	30	23
4. 1st tillage (bullock labour+operator)	3.65 OD[d]	50	175	3.5 OD	70	245
5. 2nd tillage (bullock labour+operator)	2.65 OD	50	125	3.0 OD	70	210
6. 3rd tillage (bullock labour+operator)	2.45 OD	50	125	2.5 OD	70	175
7. 4th tillage (bullock labour+operator)	2.3 OD	50	100	2.5 OD	70	175
8. Labour for planting	11 MD	20	220	9 MD	25	225
9. Labour for 1st hoeing	14.0 MD	20	280	12.4 MD	25	310
10. Labour for 2nd hoeing plus hilling	24.0 MD	20	480	24.75 MD	25	619
11. Labour for fungicide application	1.5 MD	50	75	1.5 MD	60	90
12. Guarding potato (plant and tubers) on the field	2 months	200	400	2 months	200	400
13. Amount of fertilizers – DAP	100 kg	10.55	1,055	100 kg	10.52	1052
14. Amount of fertilizers—urea	75 kg	8.88	666	75 kg	8.86	665
15. Fungicide application frequency[e] (on 0.5 ha)	3 times	630	1,890	3 times	630	1,890
16. Lifting tubers (bullock labour+ operator)	4.5 OD	50	225	4.55	70	319
17. Labour for harvesting [f]	10.19 MD	20	204	16.08 MD	25	402
18. Transport cost of potato produced on 0.5 ha	8 Mg	70	560	9 Mg	30	270
19. Cost of grading and store loading[g]	8 Mg	20	160	9 Mg	15	135
20. Storage cost ETB/Mg (net seed (at 100%[h])	8 Mg	200	1,600	9 Mg	178	1,600
21. Total cost of own small seed potato [1+2+…+20]	8 Mg	–	11,101	–	–	11,396
22. **Cost of own small-sized seed (ETB/Mg)**	–	**1,388**	–	–	**1,266**	
B Own mixed-sized seed potato						
23. Seed (seed at 3.1 Mg/ha in Jeldu and 2.6 Mg/ha in Welmera) for 0.5 ha	1.55 Mg	2,500	3,875	1.3 Mg	2,800	3,640
24. Cost of Mg of seed transportation to the field (ETB)	1.55 Mg	60	93	1.3 Mg	30	39
25. Labour for harvesting[f]	17 MD	20	340	18 MD	25	450
26. Cost of transport	13.5 Mg	70	945	11.0 Mg	30	330
27. Cost of grading and store loading	13.5 Mg	20	270	11.0 Mg	15	165
	13.5 Mg	118.5	1,600	11.0 Mg	145.5	1,600

Table 4 (continued)

Item	Jeldu			Welmera		
	Quantity	Unit cost	Total cost	Quantity	Unit cost	Total cost
28. Storage cost, in ETB/Mg (net seed (at 100%)						
29. Total cost of own mixed-sized seed [1+(4 to 16)+(23 to 28)]			13,949			13,315
30**. Cost of own mixed-sized seed (ETB/Mg)**	–	**1,033**	–	–	**1,210**	–
C. Own medium-sized seed potato						
31. Seed (seed at 2.4 Mg/ha in Jeldu and 2.0 Mg/ha in Welmera) for 0.5 ha	1.2 Mg	3,211	3,853	1.0 Mg	3,723	3,723
32. Transportation of seed to the field (ETB)	1.2 Mg	60	72	1.0 Mg	30	30
33. Labour for harvesting	21.2 MD	20	424	22.6 MD	25	565
34. Transport produce	16.65 Mg	70	1,166	12.65 Mg	30	380
35. Cost of grading and store loading	16.65 Mg	20	333	12.65 Mg	15	190
36. Storage cost ETB/Mg (net seed (at 70.0% for Jeldu and 78.6% for Welmera)	11.66 Mg	137	1,600	9.94 Mg	161	1,600
37. Value of tuber not used as seed (ETB 800 per Mg in Jeldu and ETB 1000 per Mg in Welmera)	4.99 Mg	–	−3,992	2.71 Mg		−2,710
38. Total cost of own medium-sized seed [1+(4 to 16)+(31 to 37)]	–	–	10,282	–	–	10,869
39. **Cost of own medium-sized seed (ETB/Mg)**	–	**882**	–	–	**1,093**	–

[a] Cost of capital is not included because bank interest rate (3% per annum) was lower than the inflation rate (>20%)

[b] ETB represents Ethiopian Birr (USD 1 was equivalent to ETB 17 on August 15, 2011)

[c] Mg represents mega gram

[d] OD represents ox day (1 ox day in Jeldu and Welmera was ploughing of land for 5 h with a pair of oxen)

[e] One fungicide application comprised 1.50 kg Ridomil MZ 63.5% WP (factory recommendation is 3 kg/ha per application)

[f] Labour data required for harvest were based on the labour data for medium sized seed and adjusted for the lower yields

[g] Grading and store loading in this case is not sorting but differentiating the good tuber from bad tubers and loading store

[h] Seed growers of small-sized seed potato were expected to use the whole produce for seed, and the same held true for seed growers of mixed-size seed potato

Table 5 Cost[a] (in ETB[b]) of production and post-harvest management of seed potato that could be produced on 0.5 ha in two districts

Attributes	Jeldu[c]			Welmera[c]		
	Quantity	Unit cost	Total cost	Quantity	Unit cost	Total cost
Seed source and seed size (amount of seed in Mg[d])						
Own-small	0.85 Mg	1,388	1,180	0.75 Mg	1,266	950
Own-mixed	1.55 Mg	1,033	1,601	1.30 Mg	1,210	1,573
Own-medium	1.20 Mg	882	1,058	1.00 Mg	1,093	1,093
Market-small	0.85 Mg	1,000	850	0.75 Mg	1,300	975
Market-mixed	1.55 Mg	1,200	1,860	1.30 Mg	1,800	2,340
Market-medium	1.20 Mg	1,500	1,800	1.00 Mg	2,000	2,000
Institution-small	0.85 Mg	2,000	1,700	0.75 Mg	2,500	1,875
Institution-mixed	1.55 Mg	2,500	3,875	1.30 Mg	2,800	3,640
Institution-medium	1.20 Mg	3,300	3,960	1.00 Mg	3,760	3,760
Storage method (capacity in Mg)						
Local	–	0	0	–	0	0
DLS[e]	1	16,000	16,000	1	16,000	16,000
Sprouting method						
De-sprouted	1.2 Mg	12	14.4	1.0 Mg	15	15.0
Special action	1.2 Mg	120	144	1.0 Mg	170	170
In store	1.2 Mg	0	0	1.0 Mg	0	0
Tillage frequency for 0.5 ha						
Three	8.7 MD[f]	50	435	9.25 MD	70	648
Four	10.8 MD	50	540	11.75 MD	70	823
Five	12.9 MD	50	645	14.25 MD	70	998
Planting date						
Labour required for hoeing/hilling in earlier than recommended period (a)	38.0 MD	20	760.0	37.5 MD	25	937.5
Fungicide applications frequency in earlier than recommended period (b)	2 times	630	1,260	2 times	630	1,260
Cost of earlier than recommended period ($a+b$)	–	2,020	–	–	2,197.5	–
Labour for hoeing combined with making hills in recommended period (c)[g]	57 MD	20	1,140	56.25 MD	25	1,406.25
FA[h] frequency in recommended period (d)[i]	3 times	630	1,890	3 times	630	1,890
Cost of recommended period (c+d)	–	3,030	–	–	3,296.25	–
Hoeing frequency and hill size						
Once and small	19 MD	20	380.0	18.58 MD	25	464.5
Twice and small	33 MD	20	660.0	30.98 MD	25	774.5
Twice and big	38 MD	20	760.00	37.15 MD	25	928.75
Interaction between FR[j] and FA						
Below recommended—DAP (e)	51.00 kg	10.55	538.05	48.10 kg	10.52	506.02
Below recommended—urea (f)	36.75 kg	8.88	326.34	41.00 kg	8.86	363.26
Once fungicide application (g)	1 time	630	630	1 time	630	630

Table 5 (continued)

Attributes	Jeldu[c]			Welmera[c]		
	Quantity	Unit cost	Total cost	Quantity	Unit cost	Total cost
Labour for fungicide application (h)	0.5 MD	50	25	0.5 MD	60	30
Labour for fertilizer application (i)	0.5 MD	20	10.0	0.5 MD	25	12.5
Below recommended FR and once FA (e+f+g+h+i)	–	–	1,529.39	–	–	1,541.78
Below recommended FR and twice FA (e+f+2 g+2 h+i)	–	–	2,184.39	–	–	2,201.78
Below recommended FR and thrice FA (e+f+3 g+3 h+i)	–	–	2,839.39	–	–	2,861.78
Recommended—DAP (j)	97.5 kg	10.55	1,028.63	97.5 kg	10.52	1,025.70
Recommended—Urea (k)	82.5 kg	8.88	732.60	82.5 kg	8.86	730.95
Recommended FR and once FA (j+k+g+h+1.5i)	–	–	2,431.23	–	–	2,435.40
Recommended FR and twice FA (j+k+2 g+2 h+1.5i)	–	–	3,086.23	–	–	3,095.40
Recommended FR and thrice FA (j+k+3 g+3 h+1.5i)	–	–	3,741.23	–	–	3,755.40
Above recommended—DAP (m)	107.60	10.55	1,135.18	111.25	10.52	1,170.35
Above recommended – Urea (n)	105.70	8.88	938.62	99.50	8.86	881.57
Above recommended FR and once FA (m+n+g+h+1.5i)	–	–	2,743.80	–	–	2,730.67
Above recommended FR and twice FA (m+n+2 g+2 h+1.5i)	–	–	3,398.80	–	–	3,390.67
Above recommended FR and thrice FA (m+n+3 g+3 h+1.5i)	–	–	4,053.80	–	–	4,050.67

[a] Cost of capital is not included because bank interest rate (3% per annum) was lower than the inflation rate (>20%)

[b] ETB represents Ethiopian Birr (USD 1 was equivalent to ETB 17 on August 15, 2011)

[c] In both districts, seed potato is produced only once in a year and costs are pertinent to the single season in 2010

[d] Mg represents mega gram

[e] DLS represents diffused-light storage

[f] MD represents man-day

[g] Labour required for hoeing combined with making hill for recommended planting period are higher by 50% than the labour required for earlier than recommended period

[h] FA represents fungicide application

[i] FA frequency for recommended planting period are higher by 50% than FA frequency for earlier than recommended period

[j] FR represents fertilizer rate

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