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Participatory Research for Integrated Nutrient Management (INM): The Case of Potato Production in Central Highlands of Ethiopia

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Abstract
Background and Objective: Integrated use of organic and inorganic fertilizers can improve soil fertility and potato productivity. The study was initiated in the central highlands of Ethiopia to determine the influence of INM on potato tuber yield through FRG and FFS extension approach. **Materials and Methods:** Integrated Nutrient Management of potato was evaluated through both Farmers Field School and Farmers Research Group participatory research methods in Jeldu, Dendi, Welmera, and Alemaya districts during 2004-2006 to investigate the influence of inorganic fertilizer, compost and their mixture application on yield, yield components of potato. The treatments included three improved potato varieties, nationally recommended fertilizer rate of (165 kg/ha Urea and 195 kg/ha DAP) and recommended compost at a rate of 10 t/ha. The experiment was laid out as a randomized complete block design with three replications. **Results:** At all locations, regardless of potato varieties, application of inorganic fertilizer gave significantly highest yield followed by the mixture of organic and inorganic fertilizers. Application of inorganic fertilizer gave 6% over the control while inorganic fertilizer application gave 45% yield advantage over the control. The mixture of organic and inorganic fertilizer gave 20% less tuber yield as compared to inorganic applied treatment but gave 19% and 25.3% more yields over the organic and the control, respectively. Inorganic fertilizer gave 37% more tuber yields over the organic treatment and 16% more yield over the mixed fertilizer treatment. However, the mixture of organic and inorganic fertilizers gave 18.1% over the organic fertilizer applied treatment. Potato variety Degemegn gave the highest tuber yields in both seasons 2005 and 2006 as compared to variety Jalenie and Menagesha. In general, application of inorganic fertilizers leads to higher tuber yields in all locations and in all varieties except the yield obtained at Jeldu site on 2005. **Conclusions:** Regarding the treatments, inorganic fertilizer was the top yielder in most of the locations and varieties and mixed fertilization was the second followed by organic composting. Hence resource poor farmers could adopt the mixed approach which is less expensive. Therefore, use of compost as fertilizers will have positive effects beyond the potato season due to its slow releasing of nutrients and will reduce the cost of production giving comparable yields with the one acquired using inorganic fertilizers.
Keywords: Integrated Nutrient Management, Farmer Research Group, Farmer Field School, Soil fertility, Potato

INTRODUCTION

Potato (*Solanum tuberosum* L.) requires a variety of plant nutrients for growth and development. Nitrogen, phosphorus and potassium are the most important among the elements that are essential to potato [1]. In Ethiopian the traditional farming system coupled with poor natural nutrient management resulted in shallow and poor soil fertility. Low soil fertility in general and deficiency of Nitrogen (N), Phosphorus (P) and Potassium (K) in most Ethiopian soils in particular is the most important constraint limiting potato production in Ethiopia [2]. The authors reported that, the soil fertility decline is attributed to continuous cropping, abandoning of fallowing, reduced crop rotation, removal of nutrients together with the harvested crops, reduced use of animal manure and crop residues due to their use as a fuel, which should be added to the soil and erosion coupled with low inherent fertility. Though in recent years farmers are aware about the role of inorganic fertilizer in improving the fertility status of the soil, they don't apply as required because of high price.

Low soil fertility is one of the most important constraints limiting potato production in Eastern Africa and hence accelerated and sustainable agricultural intensification is required for suitable potato production [3]. Fertility of most Ethiopian soils has already declined due to continuous cropping, abandoning of fallowing, reduced use of manure and crop rotation. The use of animal manure and crop residues for fuel and erosion coupled with low inherent fertility are among the main causes for decreasing soil fertility [4]. Farmers in central high lands mostly apply both organic and inorganic fertilizers to overcome the problem and increase yield. The use of animal manure is an alternative source of organic fertilizer mostly practiced by farmers. Soil productivity is dependent upon soil physical, chemical and biological characteristics. Continuous cultivation of arable land without nutrient inputs results in degraded soils, accelerated soil erosion, depletion of soil nutrient reserves, reduced soil organic matter contents, loss of soil physical structure, and reduced crop productivity [5]. Soil nutrient depletion on smallholder farms has been cited as the biophysical root cause of the declining food production in Africa [6].The soil fertility depletion problem could be overcome if the removal of nutrients resulting from harvests and other losses were being replaced. According to Sanchez [7], soil fertility depletion in small-scale households is largely consequents of socio-economic constraints and policy distortions. It can also be assumed that this also applies to adoption of soil fertility management practices. Soil fertility depletion results from both internal and external flows of nutrients and is often expressed as nutrient deficient patches from outfields.

According to Muriithi and Irungu [3], low soil fertility is one of the most important constraints limiting potato production in Eastern Africa. Soil fertility replenishment in Sub Saharan Africa (SSA) is increasingly viewed as critical to the process of poverty alleviation [8]. To overcome the problem of soil fertility, integrated nutrient management (INM) seeks to maximize the complementarily of mineral and organic nutrient sources [9]. INM is emerging as an important approach in improving the productivity of soils in smallholder systems. Integrated nutrient management (INM) is an approach that involves the management of both organic and inorganic plant nutrients for optimal production of cultivated crops, forage, and tree species, while conserving the natural resource base essential for long-term sustainability [10]. Moreover, Javaria and Khan [11] stated that, integrated nutrient management (INM) integrates the use of all natural and man-made sources of plant nutrients, so that productivity and nutrient status of food increases in an efficient and environmentally benefiting manner without sacrificing soil productivity of future generations. The use of organic farming is getting high importance in Ethiopia, where the international trade in organic product is increasing, export of organic coffee can be cited as a case.

The role of mineral fertilizers requires special attention within INM strategies of these systems because of farmers' strong orientation towards optimizing available organic resources. Fertilizers are not considered the principal sources of farm nutrients but, rather as one of a "menu" of interventions to be employed and combined given the changing circumstances of available organic and financial resources. The use of chemical fertilizer is a recent phenomenon in Ethiopia, i.e. it started in the late 1960s along with the launching of integrated agricultural programs and projects [12]. For sustainable crop production integrated use of inorganic and organic fertilizers has proved to be highly beneficial [13]. Moreover, INM reduces erosion, improves water infiltration, soil aeration and plant root growth, Moreover, it minimizes the risk of downstream flooding [10]. Integrated nutrient management can reduce plant requirements for inorganic nitrogen fertilizer, and reduced use of purchased fertilizer nutrients can result in a significant saving of scarce cash resources for small farmers. It also ensures the conservation and efficient use of native soil nutrients, recycling of organic nutrient flows, enhancing biological nitrogen fixation and soil biological activity and addition of plant nutrients [14]. In developing countries like Ethiopia, accelerated and sustainable agricultural intensification is required. Farmers should tackle this problem through the integrated nutrient management, which amend the soil environment. Integrated nutrient and soil fertility management is rapidly also becoming more accepted by development and extension programs in SSA, and most importantly, by smallholder farmers [8].

Negative nutrient balance is a feature of African farmlands due to the poor state of replenishment of nutrients lost [15,16,17], inter alia to crop harvesting. According to Sanchez [17], soil fertility exhaustion is the root cause of declining food production in smallholder farms of tropical Africa with fertility depletion rates 7 times larger than annual fertilizer imports. Ethiopian soils could stand a good chance of being the best example for nutrient depletion. In, Ethiopia, it is reckoned that both the rate of soil nutrient replenishment and the balance between N and P nutrients in the fertilizer applied were extremely, inadequate. Thus, average nutrient depletion in East Africa, particularly of Ethiopia is estimated to be around 47–88 kg/ha/year in general and 100 kg/ha/year in particular on the highlands [18]. Major factors contributing to such depletion are soil erosion, fixation of phosphorus and leaching in respect of nitrogen and potassium, further accelerated by deleterious land use practices resulting from high population pressure. However, it is estimated that the rate of nutrient recycling in Ethiopian highlands is generally low with 50-80% of the dung and 70-90% of the crop residues removed for use as fuel in household energy consumption, for construction or for use as animal feed. On average only about 1 ton per ha of farmyard manure is returned to the soil [19] and supplying only about 2.5 kg N and 0.3 kg P [20].

The current average potato yields in Eastern Africa has been reported to be about 8t ha^{-1} [21], which is well below the yields of 25t ha^{-1} attained by some progressive smallholder farmers, harvesting in the same soils and under the same rain fed conditions in these countries. The low level of potato production in Ethiopia is associated with low soil fertility and absence of deliberately replenishment of the nutrients to the agricultural soils in the cropping cycle after crop harvest. Shalini [22] described that, one of the contributing factors to this low yield is the inadequate application of proper agronomic management practices particularly in fertilizer and manorial use by potato growers. Potatoes are gross feeders, requiring large quantities of fertilizers, partly on account of their limited and shallow root system and partly because they have to bulk up yield. However, intensive use of only chemical fertilizers without organic has created a number of problems which have significantly affected soil fertility and potato productivity. According to Shalini [22], application of organic manures increased uptake of N, P and K over application of inorganic fertilizers alone. The authors also revealed that, integration of organic with inorganic fertilizer had a marked effect in increasing growth and ultimately yield of knolkhol and also in maintaining soil fertility and availability of nutrients in soil after harvest. The result of several long-term experiments in different cropping systems also revealed that, long-term sustainability of productivity in intensive cropping system could be achieved only through integration of inorganic and organic source of nutrients. The use of organic manure as a fertilizer in developing countries like Ethiopia has received much attention from economic point of view. Therefore, the study was initiated in the central highlands of Ethiopia to determine the influence of INM on potato tuber yield through FRG and FFS extension approach.

2. MATERIALS AND METHODS

2.1. Description of the study site

The study was conducted in three zones of Oromia region, central highlands of Ethiopia. Four districts namely, Jeldu, Dendi and Wolemera districts of West Shewa Zone, and Alemaya district of East Hararghe Zone were selected for the farmer level experiment based on importance of the crop in these areas. All the districts are characterized by mixed crop-livestock farming systems mainly representing highland agro-ecologies. Jeldu, Dendi and Wolemera are located at a distance of 130, 100 and 45kms West of Addis Ababa, respectively while Alemaya district is located at a distance of 525kms East of Addis Ababa. During the study, seven FFS and twenty one FRG were organized by during the project life span. Thus, a total of 175 and 105 farmers took part in integrated nutrient management through FFS and FRG approaches, respectively.

Selection of Participant Farmers: The farmers that participated in FFS and FRG were selected by contacting Kebele (the smallest administrative unit in the country) leaders in collaboration with development workers of district Agriculture and Rural Development Office. Initially invitation of meeting was announced by chairman of the Kebele to the farmers in the village and then the facilitator explained the details of the FFS and FRG process to the farmers. Then, the farmers attending the meeting were invited to register voluntarily at no cost following the meeting after they clearly understood the objectives and importance of FFS and FRG for learning and research. After the process of registration, some informal meetings were carried out with registered farmers to select the place where the experiment to be conducted.

Farmers Field School (FFS): FFS is a participatory research approach with high farmer involvement that involves the collegial and self-initiated types of participatory research. There are field sessions to be conducted and the role of the facilitator is very high. It is a method where the farmers' knowledge is valued as much as the technical knowledge and where the synthesis of both types of knowledge generates a critical perspective of what happens in nature. That are, it generates questions and curiosity. In short FFS is a methodological process of learning through discovery and participatory research that develops the farmers' skills for making appropriate decisions oriented to their needs.

Farmers Research Group (FRG): The FRG method was designed to be a participatory approach with less number of farmer and less facilitator involvements on the study. It included groups of only five participants, with the aim of disseminating research results to other community members in a later stage. In addition, unlike the FFS approach, there were no field sessions in the FRG approach (less emphasis on training). Participant farmers did not influence the treatments in the experiment and the group did not have formal structure necessarily. Participants only met on specific occasions to perform agronomic practices following the phonology of the crop. The main characteristic of this method was the lower number of field sessions of about 5-8 as compared to a conventional FFS which has about 12 sessions. In this participatory research approach the facilitator acted as a supervisor and interacted with the farmers less frequently.

Treatment and experimental design: This participatory experiment was conducted in Randomized Complete Block Design with three replications. In the FFS, the replications were put together in one field while in the FRG different farmers fields were considered as replications. An inter row spacing of 0.75m and an intra row spacing of 0.3m was used for planting. The plot size was 3.75m X 6m. Both organic and inorganic fertilizers were used in this study. The inorganic fertilizers included (DAP 195 Kg/ha & Urea 165 Kg/ha) while the organic source was cow manure, which was rotten and fermented three months before application. The manure was incorporated into the soil in the respective plots immediately after ploughing, and then incorporated into the soil. The treatments were:

- Organic fertilizer application (10 tha^{-1})
- Inorganic fertilizer application (DAP 195 Kg/ha & Urea 165 Kg/ha)
- Combination of (half recommended rates) for organic and inorganic fertilizer application
- Three improved potato varieties: Degemegn, Menagesha and Jalenie released by national potato research
- Zero fertilizer application (Control)

During the implementation of the experiment responsibility was shred among the stakeholders and roles and responsibilities of the facilitators and the participant farmers were described (Table 1).

Table 1: Roles and responsibilities of FFS Facilitators and Participant Farmers

Facilitators	Participant Farmers
Organization of FFS and FRG	Allocation of experimental plots
Giving orientation or facilitation to participant farmers on the activities	Management of the experiments
Designing the experiments with participant farmers	Undertake cultural practices
Implementation of experiments with participants	Construct potato storage structures
Official opening of the field schools	Evaluate the experimental results
Run Weekly field sessions to FFS participants	Participation in data collection
Collecting data of the experiments	Participate in weekly sessions
Evaluation of technologies with farmers	
Analyze the collected data and prepare progress reports	

Data collected: Both before and after the execution of PR cases, ex-ante and ex-post surveys were conducted to assess the knowledge and attitude of participant farmers regarding the technologies and the change that they exhibited in their practice of potato farming. In order to collect data on these parameters a survey was conducted using a structured questionnaire. During the vegetative stage of the crop an evaluation by a group of researchers were organized and field evaluation was made regarding the technologies being tested. Discussions were made with the participant farmers about the field performance of the technologies. On the other hand, participant farmers have periodically evaluated the technologies at different growing stages of the crop and drew information concerning the appropriateness of the technologies. Finally, data on potato yield was recorded at harvesting. The collected yield data was analyzed using SAS Version 9.2 statistical software [23].

3. RESULTS AND DISCUSSION

The results from FRG indicated that inorganic fertilizer application gave significantly higher yields followed by the mixture of organic and inorganic fertilizers, except in Jeldu on 2005. Averages of all treatment indicated that application of inorganic fertilizer gave 6% yield advantage while inorganic fertilizer application gave 45% yield advantage over the control. The mixture of organic and inorganic fertilizer gave 20% less tuber yield as compared to inorganic fertilizer applied treatment but gave 19% and 25.3% more yield over the organic and the control, respectively (Table 2). In line with this study [24] reported that, the application of farm yard manure (FYM) in combination with phosphorus resulted to the reinforcement of FYM by P application. Similar results were reported by Ahn, [25]; inorganic phosphate when applied in combination with FYM reinforces the generally low phosphate in FYM. Thus the yield of potatoes was proportional to the amount of P application. Abay and Tesfaye [26] reported that application of organic/compost did not significantly influence potato tuber yield on the first year of its application. However, yield increasing trend was observed with increasing application of compost, which is in agreement with the findings of Assefa [27] who obtained increased maize yield with increased application of farm yard manure. This implies that the application of higher rates of compost is required to get the highest tuber yield provided that the availability of composting material and other prevailing conditions occur. This also justifies the need to conduct participatory research so that farmers can assess the technologies by themselves according to local conditions.

Table 2. The effect of Integrated Nutrient Management on Potato Tuber Yield (ton/ha) Through FRG at Different Locations in 2005 and 2006 Season

	Year					
	2005			2006		
	Location and Variety					
Treatment	Alemaya (Jalene)	Jeldu (Menagesha)	Wolmera (Tolcha)	Jeldu (Menagesha)	Welmera (Jalene)	Mean *
Organic	18.0	27.57	9.83	12.21	20.37	**17.59 (6)***
Inorganic	21.23	24.91	18.47	19.71	36.21	**24.11 (45.4)**
Mixed	20.25	26.37	14.87	14.72	27.74	**20.79 (25.3)**
Control	17.61	26.17	12.67	9.74	17.91	**13.24**
Mean	**19.27**	**26.25**	**13.96**	**14.1**	**20.45**	
CV %	22.91	17.70	29.25	11.58	12.56	
LSD	NS	*	*	*	**	

* yield advantage over the control

Similarly, the result of FFS sites indicated that there was also a variation in yield among varieties and treatments. Application of inorganic fertilizer gave the highest yield advantage of 55% over the control whereas application of the mixture of organic and inorganic fertilizers gave 51% more over the control. Application of organic fertilizer gave the lowest percent yield advantage compared to inorganic and the mixture of the two however, it gave 32% more yield over the control. The result reviled that, the treatment that received inorganic fertilizer gave the highest mean yield across sites except the yield obtained at Jeldu in variety Degemegne. Application of inorganic fertilizer gave 17.8% and 2.3% over the treatment received only organic fertilizer and the treatment that received the mixture of organic and inorganic fertilizer, respectively. The mixture of organic and inorganic fertilizer gave 14.5% yield advantage as compared to the treatment that received organic fertilizers (Table 3). Regardless of the varieties, variety Degemegne gave significantly highest yield in both seasons as compared to variety Jalenie and Menagesha (Table 3). In 2005 variety Degemegne gave 5% more tuber yield as compared to Jalenie but yield differences between variety Degemegne and Menagesha did not exceeded 1%. In 2006, Degemegne gave 37.3% more tuber yield compared to the yield obtained from variety Jalenie. This yield variation may not be attributed to the yield potential of the variety but it may be due to the variation in the soil fertility status of the field.

Table 3. The effect of Integrated Nutrient Management on Potato Tuber Yield (ton/ha) Through FFS at Different Locations in 2005 and 2006 Season

Treatment	Year						
	2005				2006		
	Variety and Location						
	Alemaya (Jalene)[1]	Dendi (Menagesha)	Jeldu (Dgemegne)	Jeldu (Menagesha)	Jeldu (Dgemegne)	Welmera (Jalene)	**Mean**
Organic	20.38	26.86	27.57	19.81	36.55	19.32	**25.08 (32%)***
Inorganic	24.25	28.25	28.08	30.89	42.45	22.79	**29.45 (55%)**
Mixed	22.70	27.95	32.90	25.62	41.45	21.82	**28.74 (51.3%)**
Control	19.89	19.42	19.73	17.99	27.01	9.92	**18.99**
Mean	**21.81**	**25.62**	**27.07**	**23.58**	**36.87**	**18.46**	
CV %	29.9	9.99	12.25		8.48	38.0	
LSD	*	*	*	**	**	*	

[1] refers to the name of potato varieties, * yield advantage over the control

In general, application of inorganic fertilizers leads to higher tuber yield in all locations and in all varieties except the yield obtained at Jeldu site in 2005, where mixed use of organic and inorganic fertilizer gave 14% more yields as compared to inorganic fertilizer applied treatment. But mean tuber yield differences between inorganic and mixed fertilizer treatments were not significant. In line with this experiment [3], reported that application of inorganic fertilizer in the form of DAP at the rates of 90 kg N/ha + 230 kg P_2O_5 significantly increased the vigor of the potato plants compared to the other treatment. This study also indicated that there were significant responses to application of inorganic fertilizer to the potato crop when compared to the use of FYM alone. Application of organic fertilizers gave about 7% more tuber yield as compared to the control plot, which did not justify the marginal cost of preparing and using organic fertilizers. However, this type of fertilizers may have positive effects beyond the potato season. As described by [28], FYM also increase the uptake of N, Fe and Zn and also increase P uptake. In addition, Nitrogen, Phosphorus and Potassium uptake by plants increase with increase in FYM application [29]. This explains why tuber yields increase with increasing FYM at any given level of P application. Although the nationally recommended fertilizer rate gave significantly the highest yield, still it is not the optimum rate at which maximum yield can be obtained; yield could be increased if more fertilizer was added. This indicates that site-specific fertilizer recommendation for each location is required. Moreover, the importance of FYM is being realized again because of the high cost of commercial fertilizers and its long term adverse effect on soil chemical properties. Besides supplying macronutrients and micronutrients to the soil [30], FYM also improves the physico-chemical properties of the soil [30]. However, unless it is integrated with inorganic fertilizers, the use of farmyard manure alone may not fully satisfy crop nutrient demand, especially in the year of application [31]. Animal manures are also useful in improving the efficiency of fertilizer recovery thereby resulting in higher crop yield [32].

To evaluate and promote the improved potato production technologies participatory research methods were used. These are Farmer Field Schools (FFS) and Farmers' Research Groups (FRG). These approaches were selected because previous studies indicated that the group approach is more effective since it promotes the collective learning and exchanges that occur in group settings [33, 34]. For INM experiment, the farmers in all nutrient management practices who hosted FFS experiment incurred 57% – 65% more cost than the farmers who hosted FRG experiment. The higher cost of production in FFS approach was mainly associated with costs of facilitation. This was because, in FFS approach the facilitator makes frequent visits to the participants and the involvement of participant farmers in the FFS experiment and the time they spent was also higher than participants of FRG approach. As a result, more seed yield was obtained from adopting FFS than FRG approaches under all nutrient management practices. The seed yield obtained in FFS approach ranged from 14.90 – 24.94 tons/ha and in FRG approach, it ranged from 12.48–20.07 tons/ha (Table 4). The farmers obtained more seed yields from inorganic nutrient management practice than other options. Almost similar trend was also observed from ware yields obtained as indicated in Table 5.

Table 4. Seed yield tons/ha of graded potato varieties for INM

Nutrient management practices	**Participatory Research Methods**			
	FFS		FRG	
	n	Mean Yield (t/ha)	n	Mean Yield (t/ha)
Organic	21	19.18	17	13.39
Inorganic	21	24.94	17	20.07
Mixed	21	23.29	17	17.41
Control	21	14.90	17	12.48

Table 5. Ware yield tons/ha of graded potato varieties (second grade yield) in INM

Nutrient management practices	**Participatory Research Methods**			
	FFS		**FRG**	
	n	Mean Yield (t/ha)	n	Mean Yield (t/ha)
Organic	21	3.58	17	3.04
Inorganic	21	5.06	17	4.97
Mixed	21	4.46	17	4.26
Control	21	2.81	17	3.30

The farmers graded the potato tubers into seed grade and ware grade. The tubers graded for seed purposes were sold at premium price while the tubers graded for ware were sold at lower price. According to the findings, a net profit advantage of 50% more is obtained by adopting FFS approach than FRG approach (Table 4 & 5). In FFS approach, the farmers were empowered with knowledge that enables them to produce potato with improved management practices. From this experiment, the farmers who hosted FFS obtained a net profit ranging from 3% – 20% over FRG experiment except in the case of control nutrient treatment (Table 6). In the case of control experiment (no external nutrient application), FRG approach obtained higher net profit than FFS approach.

Table 6. Net profit (Birr/ha) of producing graded potato in INM

Nutrient management practices	**Participatory Research Methods**				**Increment in FFS profit over FRG (%)**
	FFS		**FRG**		
	n	Mean (ETBirr[1])	n	Mean (ETBirr)	
Organic	21	23372.19	17	19445.91	20
Inorganic	21	43291.21	17	42182.85	3
Mixed	21	37364.02	17	33115.08	13
Control	21	13108.56	17	19939.77	-34

**1Birr= 21USD, 1=Ethiopian Birr (ETBirr)*

In general, even though FFS approach entailed more initial investments than FRG approach, it ensures active participation, more contact and experience sharing among the farmers. Previous studies indicated that the group approach was more effective than individuals since it promoted the collective learning and exchanges that occur in group settings [33, 34] and ensured that more people participate, thus making participatory research cost-effective and relevant to the needs of different categories of farmers [35, 36]. Moreover, initial investments on knowledge created favorable conditions to make effective productions in the seasons to come.

CONCLUSION AND RECOMMENDATION

From the study it can be concluded that the combination of organic and inorganic fertilizer is recommended for the production of high potato yields. It was also observed that FYM alone cannot result in high potato yields. The result indicated that there were tuber yield differences between FRG and FFS participatory approach though; the location and the varieties were almost similar. The justification for yield variation probably was in the FRG where the number of farmers involved to manage the crop were small; the frequency to visit their trial field is limited, even the knowledge they acquire is also limited to properly implement the technology. On the other hand, numbers of farmers in the FFS are relatively more hence; the group may not face labor shortage, that helps to manage the crop be better. In FFS approach the group visits the field frequently so that any problem related to their crop would be solved on time and in addition the farmers in FFS have more access to the knowledge related to the technology adoption and develop confidence on the technology. This implies that the FFS approach has enriched the knowledge base of the farmers to enable them manage their potato crop in a better practice than they used to do before using FFS approach. Conversely, the contribution of FRG approach to strengthen farmers' knowledge base was limited than FFS approach. According to the findings, adopting FFS approach is a worthwhile investment. It builds the knowledge base of the farmers to help them manage their enterprises in a better way than they used to do before FFS. Moreover, FFS has a considerable spillover effect to enable the farmers to manage other enterprises in a more scientific and improved practice than the condition before FFS and also suggested to be promoted to potato production technologies for major potato producing areas of the country.

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