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Research Article

Effect of Consorted PGPMs and Mineral Fertilizer on Grain Yield of Wheat (*Triticum aestivum L.*) and Malt Barely (*Hordium vulgar L*) in the Central Highlands of Ethiopia

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Abstract

A field experiment was conducted at Welmera, Ada'a Berga and Kersa Malema districts of Ethiopia during 2016 and 2017 cropping seasons to evaluate the effect of PGPMs consortium (Panoramix product) on yield of wheat and malt barely. The treatments were untreated control, Recommended NPS, Panoramix coated seed, Imidalm/Apron Star and Panoramix coated seed, Panoramix + Recommended NPS, and Imindalem/Apron Star + Panoramix + Recommended NPS and laid out in randomized complete block design with four replications. Statistically significant differences ($P \leq 0.05$) were observed among treatments for grain yield of wheat and malt barely in all locations and seasons. The highest wheat grain yields at Welmera and Kersa Malema, and Ada'a Berga were 4617, 3080 and 4360 kg ha-1, respectively and obtained from Panoramix + 182 kg NPSB and 55.4 kg urea ha-1. In malt barely, the average grain yield (3554 and 2563.6 kg ha-1) at Welmera and Kersa Malema, respectively were obtained from Apron Star + panoramix + 121.08 kg NPSB and 39.16 kg urea ha-1 despite at par with the sole recommended NPS, which had the peakiest average grain yield (2749.6 kg ha-1) at Ada'a Berga. The result generally confirmed, PGPMs consortium (panoramix product) co-application with mineral fertilizer on wheat and malt barely did not show agronomic and economic superiority over sole recommended mineral fertilizer. But, at Welmera, paronamix + Apron star + Recommended NPS treatment was feasible though not showed significant grain yield change.

Keywords: Grain yield; Mineral fertilizer; Panoramix; PGPM; Soil

Introduction

Agriculture accounts for 41% of the Gross Domestic Product (GDP), 85% of total export and is providing the source of livelihood for the great majority (over 80%) of the Ethiopian population of 102 million in 2017 [1]. However, the sector is still characterized by low productivity, dominated by subsistence, low input and low output rainfed farming systems in which biotic and abiotic factors periodically reverse performance gains with adverse effects on household food security particularly on the staples [2]. Ethiopia is one of the largest wheats and malt barely producers in sub-Saharan Africa. However, wheat yield levels are low with a national average of about 2.2t/ha, which is well below yields obtained from research stations, i.e., 5t ha-1 in 2017 [3]. Diagnostic studies with farmers in the Ethiopian highlands have identified declining soil fertility as a key driver of low yields of field crops due to continuous nutrient uptake of crops, low fertilizer use and insufficient organic matter application [4-6]. Studies on nutrient cycles in the Central highlands of Ethiopia revealed that the nutrient balance in different soil fertility classes varied from -20 to -185 kg N, from +11 to -83 kg P and from +23 to -245 kg K ha-1 yr-1 [4].

Studies often showed that the use of chemical fertilizers in Ethiopia have contributed to crop yield growth to date [7]. Despite the potential for further improvement, fertilizer is applied by less than 45% of farmers, on about 40% of area under crop, and mostly at below optimal dosage levels [8] in the country. Limited access to credit and limited supply of fertilizers as well as continued price hike were contributing to the sub-optimal use [9]. There is evidence to suggest that fertilizer applied in Ethiopia is not as effective as potential suggests while application rates are yet higher than the average for sub-Saharan Africa [10]. For example, the nutrient use efficiency (NUE = kg yield per kg nutrient) of maize in Ethiopia is 9 to17 kg of grain per kg of applied N, while in Kenya and Tanzania equivalent NUEs range from 7 to 36 and 18 to 43 [11].

Given the reported negative environmental impacts of chemical fertilizers and increasing costs, utilization of PGPM [12] along with inorganic fertilizers is advantageous for sustainable agricultural practices via nutrient cycling and use efficiency improvement [13]. Unfortunately, little attention has been given to the integration of plant growth promoting microbes (PGPMs), which cover plant growth promoting rhizobacteria (PGPR), N2 fixing cyanobacteria, mycorrhiza, plant disease suppressors, stress tolerance endophytes, and biodegrading microbes [14]. The use efficiencies of P and N nutrients of were advanced in 10-30% by the synergistic interaction of PGPR and AMF [15]. As high as 50-70% crop yield increase were reported from abroad by using PGPM [16,17] despite crop and soil specificities [18,19]. Their reported mode of action has been synthesizing particular compounds for the plants [16], facilitating the uptake of certain nutrients from the soil [20], and suppressing pathogens and growth inhibitors [21]. Nevertheless, information/technology with regards to cereal biofertilization is hardly available in Ethiopia. Therefore, the study was intended to investigate the effects of consorted AM, bacillus and trichoderma product on growth and grain yield of wheat and malt barely across soils and seasons.

Materials and Methods

Site and material description

The seed coating biological product is referred to as Panoramix and is consorted of Endomycorrhiza, Bacillus, and Trichoderma species) and additives such as (vitamins, fulvic and humic acids, extracts from algae and vegetable oil etc). Apron Star 42 WS and Imidalm T 450 WS are fungicide-insecticide materials with a broad spectrum use through seed dressing (systemic action) [22] and are registered materials in Ethiopia [23]. The evaluation of Panoramix was carried out at Holetta Agricultural Research Center (on station), Ada'a Berga (on farm) and Kersa Malema (on-farm) from 2016-2017 cropping season. The three sites were supposed to represent high rain fall-Nitisols, on-station; high rain fall-Nitisols, on-farm, and mid land-Vertisols, respectively. The soil physicochemical characteristics of the experimental sites were shown in Table 2 (Figure 1).

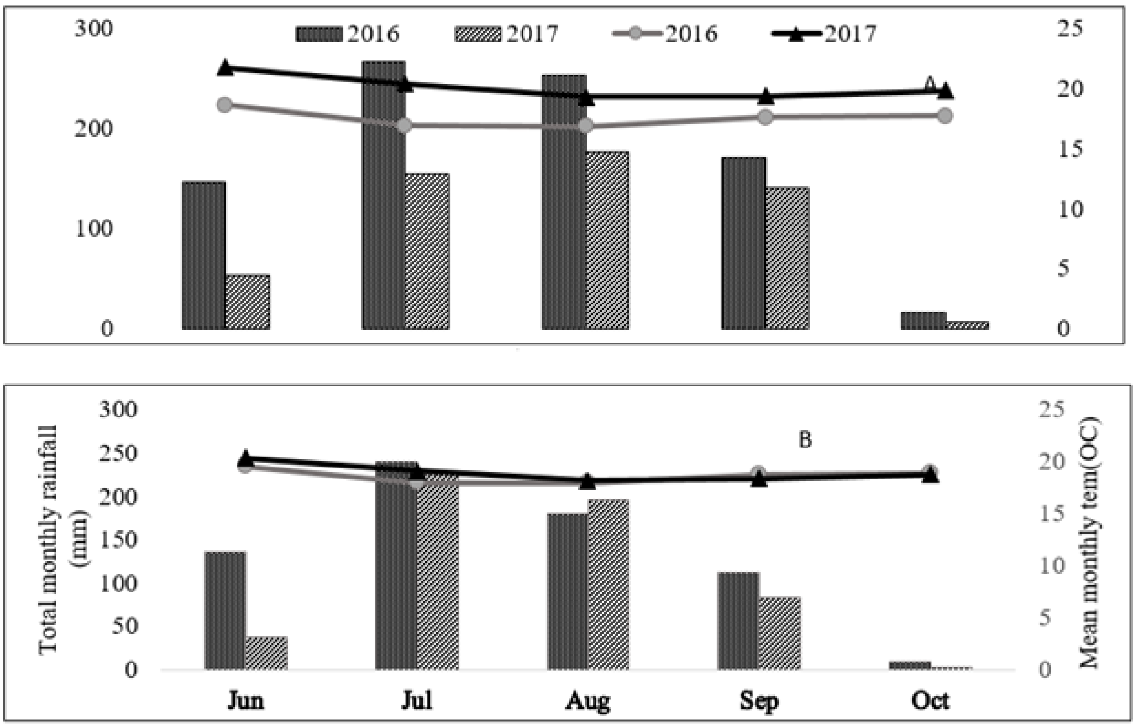

Figure 1: A and B: monthly air temperature and rainfall records of Kersa Malema and Welmera/Ada'a Berga districts during the trial periods (Hint: the lines and bars indicate the and mean monthly temperature and monthly rainfall, respectively).

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Table 1: Treatment lists in abbreviated forms for both crops.

No	Wheat Treatment	Malt Barely Treatments
1	Control (no input)	Control (no input)
2	RMF (182 kg NPSB + 55 kg urea ha^{-1})*	MF (121.08 kg NPSB + 39.16 kg urea ha^{-1})**
3	P	P
4	P + I	P + A
5	P + RMF	P + RMF
6	P + RMF + I	P + RMF + A

RMF = recommended mineral fertilizer; P = Panoramix; I = Imidalm; A= Apron star; * = NPSB and urea rates are assumed to cater 60 N and 30 kg P ha-1, recommended rate for wheat; **NPSB and urea rates were assumed to cater 41N and 20 P kg ha-1, recommended rate for malt barely on the study sites.

Table 2: Average value of the major soil physicochemical characteristics of the experimental locations.

Location	pH	TN (%)	OC (%)	C:N	Av P (ppm)	Ex. Acidity (meq/100g)
Kersa Malema	6.5	0.08	1.06	13	9.2*	0.024
Ada'a Berga	5.6	0.09	1. 12	12	6.4	0.15
Welmera	4.46	0.18	1.45	8	6.7	0.26
Test method)	1:2.5 (soil to water)	Kjeldhal	Walkley &Black		Bray II	Van reeuwijk, L.P.

*= Olsen method. Averaging was made since fields in both years were adjacent in each site and yet not much difference was observed.

Treatments and data management

The treatments were set by systematically combining panoramix with recommended mineral fertilizer and the fungicide-insecticides so as to test their synergy and effect on grain yield with regards to the reference practice (recommended mineral fertilizer). The control was meant for economic analysis purpose. The treatments were laid out in randomized complete block design (RCBD) with four replications in all locations and growing seasons. The plot size was 3 m × 4 m (12 m2). The spacing between blocks, plots and rows were 1, 0.5 and 0.2 m, respectively. Wheat (variety Alidoro) and malt barely (var. Hibon) seed lots were weighted on 150 and 100 kg ha-1 rate and dressed in imidalm and Apron Star at 2.5 g and 0.75 g kg-1 of seed (labeled rate), respectively. Subsequently, the seeds lots were coated with well-shaken Panoramix product at a rate of 4 ml kg-1 seeds and stored in nylon bags under dark conditions for two weeks just before sowing. All agronomic practices were applied as per recommendations for the crop (Table 1).

Grain yield data was collected from the internal rows of each plots and measured after adjusting the moisture to 12% before the analysis of the variance (ANoVA). Analysis of grain yield for the different sites was done separately as averaging them having different soil properties (Table 2) and larger yield variations may not be a very meaningful approach [2]. Grain yield data was analyzed using SAS 2002 software and interpretation was made accordingly. In case of significance difference between treatments, mean separation was made at LSD value on $P \leq 0.05$. Moreover, cost benefit ratio was computed in order to determine the profitability of the product.

Results and Discussions

Soil properties explaining wheat and malt barely yields

The average surface soil nutrient status before planting differed substantially between the experimental locations (Table 2). The experimental sites of Ada'a Berga and Welmera had an average pH of 4.46, rated as strongly acidic soil condition (Hazelton and Murphy, 2007). Such pH level is common in most upland and high rain fall areas of Ethiopia where Ferralsols and Acrisols are dominant. However, lime application would not be carried out as the respective exchangeable acidity values were less than 1 meq/100g) [24]. Organic carbon (%OC) was rated as moderate while %TN was medium for Welmera and low for the rest locations. This justifies the application of N to wheat and malt barely for ensuring improved yield. The C:N ratios of both locations were between 8-13, which is favorable for decomposition of organic materials.

The average concentration of available P was not as such variable across the locations. All locations had low to very low P available rating (Mallarino et al., 2013). Thus, like N, it would be essential for farmers to apply external P source to enhance the productivity of cereals. It was reported that about 28, 15 and 10% grain yield variations of cereals such as wheat were contributed by OC, TN, and pH respectively [2].

Grain yield response of wheat and malt barely to panoramix on season base

During the 2016 growing season, statistically significant differences ($P < 0.05$) were observed among treatments for grain yield of wheat and malt barely at all locations (Table 3). Accordingly, co-application of P + RMF and P + RMF + I could not show statistically superior grain yield over the sloe RMF on both crops across all locations. Statistically similar wheat grain yield differences were obtained between AM inoculated and non-AM inoculated wheat under moderate P application [25]. In contrast, better grain yield of wheat was obtained from bacillus inoculation [26]. The bacillus might increase uptake of water and nutrients that would ultimately lead to improved nitrogen metabolism in different parts of the plant. The interaction of panoramix with mineral fertilizer in terms of enhancing the grain yield of wheat and malt barely was not promising. Even co-application of imidalm or Apron star did not alter the interaction effect of panoramix and mineral fertilizer with regards to grain yield.

Similar to 2016 growing season, significant grain yield differences among treatments were obtained across all locations during 2017. The interaction of P and RMF tends to be highly dictated rather by the crop species (Table 4). Accordingly, neither P + RMF nor P + RMF + I was able to show grain yield superiority over RMF regardless of crop and location. The PGPMs consorted in Panoramix could not enhance the grain yield of wheat and malt barely as co-applied with RMF at Welmera, Ada'a Berga and Kersa Malema districts the efficiency of mineral fertilizer. This implies that the PGPMs (sole or combined with the fungicide-insecticides) were non-interactive. They could not increase nutrient use efficiency of the fertilizers, mobilize nutrients such as P that would lead to improved metabolism and then better grain yield. In the absence of inorganic fertilizer application particularly N and P, the application of panoramix (either alone or in combination with Imidalm) were statistically at par with the untreated control (Tables 3 & 4) on both crops. This simply demonstrates that application of mineral fertilizer on less fertile soil for the production of wheat is very auspicious. Hence, the overall wheat grain yield performance in the above discussions confirms that co-application of panoramix and mineral fertilizer did not win sole mineral fertilizer application statistically.

Table 3: Response of wheat grain yield (kg ha^{-1}) to panoramix application at Welmera, Kersa Malema and Ada'a Berga districts in 2016 main growing season

Treatment	Wheat			Malt Barely		
	Welmera	Ada'a Berga	Kersa Malema	Welmera	Ada'a Berga	Kersa Malema
Control	2222b	2606b	2758c	2921d	2585b	1134b
RMF	2786ab	4237a	4598ab	3976abc	3253a	2429a
P	2191b	2528b	3298bc	3128cd	2786ab	908b
P + I/A	2126b	2853b	2768c	3397bcd	2822ab	1142b
P + RMF	2737ab	3965a	4738ab	4077ab	2751ab	2495a
P + RMF + I/A	3012a	4033a	4165abc	4516a	2825ab	2648a
LSD	661	929	1503	937	622	521
CV (%)	18	19	17	17	18	19

I= imidalm (coated on wheat); A= Apronstar (coated on malt barely); Means with the same latter in a column are non-significantly different.

Table 4: Response of wheat grain yield (kg ha^{-1}) to panoramix application at Welmera, Kersa Malema and Ada'a Berga districts in 2017 main growing season.

Treatment	Wheat			Malt barely		
	Welmera	Ada'a Berga	Kersa Malema	Welmera	Ada'a Berga	Kersa Malema
Control	2758c	3100d	1328b	2133b	900c	1688bc
MF	4598ab	4261ab	3189a	2904a	2246a	2600a
P	3298c	3256cd	1872b	2213b	733c	1317c
P + I/A	2768c	3200cd	1933b	2288b	1138bc	2279ab
P + MF	4738a	4817a	3544a	2488ab	2067a	2317ab
P + MF + I/A	4165ab	4361ab	3111a	2592ab	2358a	2479a
LSD	1551	1194	609	571	489.62	767
CV (%)	14	18	14	16	20	25

I= imidalm (coated on wheat); A= Apronstar (coated on malt barely); Means with the same latter in a column are non-significantly different.

Combined performance of wheat and malt barely under panoramix

The combined treatment mean comparison repeated similar statistical difference trend to the separate seasons. The mineral fertilizer and non-mineral fertilizer treatments appeared contrasting (Table 5). This reconfirmed simply the importance of mineral fertilizers to wheat and malt barely production across the three locations. However, the average grain yield of wheat due to application of on mineral fertilizer (i.e. the research recommended practice) and panoramix and /or imidalm with mineral fertilizer (candidate technology) did not show statistically significant differences across all the three locations.

Both sole application of panoramix and its dual use with imidalm /Apron Star were significantly inferior to RMF treatments and yet were not better than the control regardless of location and crop and season in grain yield. This confirms that Panoramix is a complementary but not alternative product to mineral fertilizers on cereals like wheat and malt barely. Besides, neither P + RMF nor P + RMF + I/A statistically surpassed sole RMF in grain yield performances on both crops in all locations. This implies that the panoramix was ineffective.

Despite the lack of statistical significance, P + RMF displayed consistent numerical superiority in wheat grain yield over the sole RMF; Welmera, Ada'a Berga and Kersa Malema districts had 399, 83 and 125 kg ha-1. In case of malt barely, P +RMF +A had absolute grain yield increment of 430 and 50 kg ha-1 over the sole RMF at Welmera and Kersa Malema, respectively (Table 5). In terms of efficacy of panoramix, Welmera > Kersa Malema > Ada'a Berga regardless of the crop type. In contrast, grain yield response variation was reported in wheat varieties to arbuscular mycorrhiza fungi inoculation [25]. This suggests that the efficacy of the current PGPMs consortium would not tend to be associated with moisture availability due to the fact that Welmera received better rainfall amount and distribution than the remaining locations (Figure 1). Instead, the soil environment, particularly the pH is supposed to influence the efficacy (Table 2). This effect would be, thus, attributed to the improvement in P uptake due to the P mobilizing effect of endomycorrhiza or P solubilization effect of the Bacillus components of the panoramix product. In fact, it was shown in some cases that mycorrhiza and bacteria confer resistance against fungal pathogens such as Pythium spp [27] or alleviate drought stress [28]. Soil pH of less than 5.5 often manifested in rendering phosphate unavailable to plant roots (P-fixation) [29] and yields of crops grown in such soils are very low [24]. On the other hand, the presence of imidalm as a pre-coating insecticide-fungicide might insured the safe growth of malt barely, which indirectly assisted the improvement of nutrient uptake and metabolism.

Cost-benefit analysis of treatments

The partial budget analysis of wheat grain yield confirmed that some treatments were dominated while some other not (Table 6). Since no beneficiary will prefer alternatives that give lower net benefits than net benefit of an alternative with lower total variable costs, the dominated treatments were eliminated from further partial budget analysis. As the marginal rate of return (MRR) for the non-dominated treatments revealed that mineral fertilizer + imidalm and sole mineral fertilizer earned > 100% at Welmera and Kersa Malema, while at Ada'a Berga, mineral fertilizer + panoramix, and sole mineral fertilizer gave >100% MRR. This implies that these treatments were best alternatives in terms of money generated per unit investment in the respective districts. Accordingly, RMF appeared to economically feasible regardless of locations. A unit investment for wheat production at Welmera, Ada'a Berga and Kersa Malema districts with mineral fertilizer returns 2.86, 5.28 and 3.42 units of money, respectively. RMF remained agronomically and economically attractive [30-32].

In case of malt barely, the marginal rate of return (MRR) for the non-dominated treatments revealed that RMF had an MRR of > 100% at Kersa Malema Ada'a Berga. But at Welmera, RMF + P + A had superior MRR (2.56 ETB/unit investment). This implies that these treatments were best alternatives in terms of money generated per unit investment in the respective districts. Accordingly, malt barely production at Ada'a Berga and Kersa Malema with mineral fertilizer (NPSB and urea) had 2.80 and 4.64 return per unit investment (Table 7).

Conclusion and Recommendations

From this work we conclude that it is possible to improve cereal yields using fertilizer application, but fertilizer recommendations need to be site and soil specific for maximum gains. The overall grain yield response of wheat and malt barely across Welmera, Kersa Malema and Ada'a Berga districts disclosed that co-application of panoramix and /or imidalm with recommended NPSB on wheat or panoramix and /or Apron Star with recommended NPSB on malt barely produced statistically similar grain yield to the sole recommended NPSB application. The RMF was economically feasible in wheat and malt barely grain yield. However, mineral fertilizer + panoramix + Apron star yielded the best economic output at Welmera. So, panoramix was not able to improve wheat and malt barely productivity in these locations and thus, not recommended for supplementary or alternative use. But at Welmera, it can be used along with mineral fertilizer and Apron star.

Table 5: Average wheat and malt barely grain yield (kg ha^{-1}) to panoramix application at Welmera, Kersa Malema and Ada'a Berga districts during 2016-2017.

Treatment	Wheat			Malt barely		
	Welmera	Ada'a Berga	Kersa Malema	Welmera	Ada'a Berga	Kersa Malema
Control	3365c	2848d	1950b	2527c	1742b	1411bc
RMF	4218ab	4277a	2955a	3124abc	2750a	2514a
P	3511bc	2869d	2051b	2670bc	1760b	1112c
P + I/A	3216c	3032c	2040b	2942abc	1980b	1777b
P + RMF	4617a	4360a	3080a	3182abc	2409ab	2406a
P + RMF + I/A	4033abc	4204a	3051a	3554a	2592a	2564a
LSD	860	719	524	785	779	528
CV (%)	22	18	19	26	25	27

I= imidalm (coated on wheat); A= Apron star (coated on malt barely); Means with the same latter in a column are non-significantly different.

Table 6: Partial budget analysis (PBA) of the treatments in Welmera, Ada'a Berga and Kersa Malema districts on wheat (Ethiopian Birr).

Treatments	GY	AGY	GB	TVC	NB	D	MC	MNB	MRR (%)
Welmera (Holeta)									
Control	3365	2860	48624	0	48624		0	0	0
MF	4218	3585	60950	3196.75	57753		3197	9129	285.57
P	3511	2984	50734	400	50334	D			
P + I	3216	2734	46471	475	45996	D			
P + RMF	4617	3924	66716	3596.75	63119	D			
P + RMF + I	4033	3428	58277	3671.75	54605	D			
Ada'a Berga									
Control	2848	2421	41154	0	41154	0	0	0	0
MF	4277	3635	61803	3284.82	58518		3285	17364	528.62
P	2869	2439	41457	400	41057	D			
P + I	3032	2577	43812	597	43215	D			
P + RMF	4360	3706	63002	3684.82	59317		3685	18164	492.93
P + RMF + I	4204	3573	60748	3881.82	56866	D			
Kersa Malema									
Control	1950	1658	28178	0	28178				
MF	2955	2512	42700	3284.82	39415		3285	11237	342.1
P	2051	1743	29637	400	29237	D			
P + I	2040	1734	29478	597	28881	D			
P + RMF	3080	2618	44506	3684.82	40821	D			
P + RMF + I	3051	2593	44087	3881.82	40205	D			

GY- grain yield; AGY= adjusted grain yield; GB= gross benefit; TCV= total cost that vary; NB= net benefit; MC= mariginal cost; D= dominated; MB= mariginal benefit and MRR= mariginal rate of return. The farm get price of imidalm (kg), panoramix (L), urea (kg), NPSB (kg), wheat (kg) were 500, 620, 13.09,13.58 ETB, respectively. Insignificant transportation (mineral fertilizer) and dressing (panoramix and imidalm) costs were considered. One ETB equals 17 USD, on average.

Table 7: Partial budget analysis (PBA) of the treatments in Welmera, Ada'a Berga and Kersa Malema districts on malt barely in Ethiopian Birr, ETB.

Treatments	GY	AGY	GB	TVC	NB	D	MC	MNB	MRR (%)
Welmera (Holeta)									
Control	2527	2148	32219	0	32219		0	0	0
MF	3124	2655	39831	2154	37677		2154	5458	253.4
P	2670	2270	34043	400	33643	D			
P + A	2942	2501	37511	1525	35986	D			
P + RMF	3182	2705	40571	2554	38017	D			
P + RMF + A	3554	3021	45314	3679	41635		3679	9416	255.9
Ada'a Berga									
Control	1742	1481	22211	0	22211		0	0	0
MF	2750	2338	35063	2214.8	32848		2215	6195	279.7
P	1760	1496	22440	400	22040	D			
P + A	1980	1683	25245	1647	23598	D			
P + RMF	2409	2048	30715	2614.8	28100	D			
P + RMF + A	2592	2203	33048	3861.8	29186	D			
Kersa Malema									
Control	1411	1199	17990	0	17990		0	0	0
MF	2514	2137	32054	2255.9	29798		2256	8210	363.9
P	1112	945.2	14178	400	13778	D			
P + A	1777	1510	22657	1647	21010	D			
P + RMF	2406	2045	30677	2655.9	28021	D			
P + RMF + A	2564	2179	32691	3902.9	28788	D			

GY- grain yield; AGY= adjusted grain yield; GB= gross benefit; TCV= total cost that vary; NB= net benefit; MC= mariginal cost; D= dominated; MB= mariginal benefit and MRR= mariginal rate of return. The farm get price of imidalem (kg), panoramix (L), urea (kg), NPSB (kg), wheat (kg) were 500, 620, 13.09,13.58 ETB, respectively. Insignificant transportation (mineral fertilizer) and dressing (panoramix and imidalem) costs were considered.

One ETB equals 17 USD, on average.

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Conflict of Interest

No conflict of interest.

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