Response of Yield and Yield Components of Field Pea to Tillage Frequency, Phosphorus Fertilization and Weed Control on Nitisols of Central Ethiopian Highlands

Getachew Agegnehu* and Hailu Beyene

Holetta Agricultural Research Center, Ethiopian Institute of Agricultural Research, P O Box 2003, Addis Ababa, Ethiopia

Abstract: The effects of tillage frequency, phosphorus fertilizer and weed control on yield and yield components of field pea (*Pisum sativum* L.) were studied in the 2003 and 2004 main cropping seasons on farmers' fields in the Chelia and Welmera Districts of west Shewa, Ethiopia. Four levels of tillage frequency (T4 = April, May, early June and at planting; T3 = May, early June and at planting; T2 = May and at planting and T1= at planting) as main plots and factorial combinations of four levels of phosphorus fertilizer (0, 10, 20 and 30 kg P ha^{-1}) and two levels of weeding (W1 = no weeding and W2 = hand weeding once) were arranged as sub-plots in split-plot design with three replications. The results indicated a highly significant positive response of mean field pea seed yield, total biomass and number of pods per plant to tillage frequency, phosphorus fertilizer and weeding treatments. Plowing twice, three and four times including the last pass for seed covering resulted in mean seed yield advantages of 38, 55 and 43%, respectively, compared to the control. Application of phosphorus fertilizer at the rates of 10, 20 and 30 kg P ha^{-1} increased mean seed yields by 30, 53 and 50%, respectively, compared to the control. Weeding once by hand increased mean seed yield by 16% compared to the unweeded check. Tillage frequency by P fertilizer and weed control interaction significantly affected seed yield. The highest mean seed yield of two years for the tillage, P fertilizer and weed control interaction was obtained from three plowings, 20 kg P ha^{-1} and weeding once by hand. The yield increment was higher by 232% compared to the control, namely planting with the first pass of ox-drawn implement, with no P application and unweeded condition. Seed yield was highly significantly and positively correlated with total biomass ($r = 0.93^{**}$), pods per plant ($r = 0.54^{**}$), plant height ($r = 0.54^{**}$), seeds per pod ($r = 0.41^{**}$) and thousand seeds weight ($r = 0.37^{**}$). The results of economic analysis indicated that the treatment with three times tillage, application of 20 kg P ha^{-1} and weeding once by hand is the best option with a marginal rate of return of 423%, which is economically the most feasible alternative.

Keywords: Field Pea; Nitisols; Phosphorus; Tillage Frequency; Weed Control

1. Introduction

Although field pea is one of the important grain legumes in Ethiopia, its productivity is low due to several factors, among which the major ones are poor seedbed preparation, untimely sowing, poor soil fertility, inadequate weed control and the lack of improved varieties (Alem *et al*., 1990; Asfaw *et al*., 1994). The primary objectives of soil tillage are to provide suitable seedbed and adequate weed control (Rao, 2000). Traditionally, farmers use the local plow for tillage operations to prepare seedbeds. However, the preparation of appropriate weed free seedbeds for crop establishment and production is a problem to field pea and faba bean productions in Ethiopia. Farmers do not practice pre-planting tillage for field pea production compared to most cereals. In most cases, field pea is sown with the first plowing. This leads for uneven germination of seeds, high weed pressure and poor plant stand, which in, the final analysis, results in reduced yields.

Research results showed that plowing frequency and weed control operation significantly increased yield of faba bean (Getachew *et al*., 2005). Hebblethwaite *et al*. (1983) reported that deep loosening of the soil profile to a depth of 90 cm resulted in a considerable increase in yields of faba bean. Increased plowing frequency reduces the occurrence and distribution of weeds (Tolera and Daba, 2004). A review by Amare and Adamu (1994) also indicated that repeated plowings significantly increased yields of field pea. The highest seed yield of field pea with a yield advantage of 62% over the control was obtained from plowing twice followed by plowing three times with a yield advantage of 37% (Amare and Adamu, 1994).

Acidic Nitisols are of wide occurrence in the highlands of Ethiopia where the rainfall intensity is high and the land has been under cultivation for many years. These soils have pH values of less than 5.5, thereby resulting in low yields. The low yields in such soils could mainly be either due to the deficiency of nutrients, such as P, Ca and Mg (Taye and Höfner, 1993; Getachew and Sommer, 2000), or due to toxicity of Al, Fe and Mn (Sharma *et al*., 1990). The growth and grain yield of field pea is affected by fertilizer application. Results of fertilizer trials indicated that field pea grain yield significantly increased over the control due to application of P fertilizer (Getachew *et al*., 2003). The application of 18/20 kg N/P ha^{-1} increased field pea grain yield by 103% compared to the unfertilized plots. Angaw and Asnakew (1994) also reported that the response of field pea to P fertilizer was very high at many locations.

Traditionally, field pea is cultivated under no weeding conditions. Rezene (1986) reported that the major reason for sub-optimal weeding of field pea is the overlapping of farm activities with other crop enterprises. However, experimental evidence indicated that significant reduction in field pea yield potential occurred because of no weeding during the beginning and post-flowering stages of the crop (Rezene, 1986, 1994). Weed competition is high, especially in fields where the land preparation is poor. The efficiency of fertilizer is also low in such fields. Piecemeal research results of these factors have shown positive effects on growth and yield of field pea. However, previous research findings were generated in research centers, with no consideration of differences in soil fertility and weed flora on farmers' fields. Another reason worth mentioning for conducting the current study is to

*Corresponding author. E-mail: get.age65@yahoo.com

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find out whether the interaction of tillage, fertilizer and weed control exists. Furthermore, economic feasibilities was not considered in recommending the combined results of tillage frequency, fertilizer and weed control for field pea production on Nitisols of the central Ethiopian highlands. Thus, the objectives of the study were to determine the: (1) effects of tillage, phosphorus fertilizer and weed control practice and their interactions on yield and yield components of field pea at two locations in West Shewa Zone, central highlands of Ethiopia, and (2) the economic feasibility of the practice for field pea production.

2. Materials and Methods

2.1. Experimental Site

The trial sites were located on the farmers' fields of Welmera and Chelia Districts of West Shewa, central highlands of Ethiopia, at an altitude of about 2400 and 2700 m above sea level, respectively. In Welmera, the long-term average annual precipitation is 1100 mm, about 85% of which is received from June to September and average minimum and maximum air temperatures are 6.1 and 21.9 °C, respectively. The farming system of the trial sites is crop-livestock mixed farming system. The major soil type of both trial sites is Nitisols.

2.2. Soil Sampling and Analysis

Selected soil chemical properties of the experimental fields, which are shown in Table 1, were determined for samples taken during planting in the soil and plant analysis laboratory of the Holetta Agricultural Research Center. Soil reaction (pH) was measured in H_2O with a liquid to solid ratio of 1:1. Likewise, total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was determined using the Bray-II method (Bray and Kurtz, 1945). Exchangeable cations and cation exchange capacity (CEC) were analyzed using the ammonium acetate method (Black, 1965).

Table 1. Some soil chemical characteristics (0-20 cm depth) of the experimental sites at Welmera and Chelia.

Parameter	Welmera	Chelia	Mean
pH (1:1 H_2O)	4.73	4.65	4.69
Total nitrogen (%)	0.19	0.31	0.25
Available P (mg kg^{-1})	8.45	6.72	7.59
Exchangeable Na (cmol(+) kg^{-1})	0.03	0.10	0.07
Exchangeable K (cmol(+) kg^{-1})	1.71	1.25	1.48
Exchangeable Ca (cmol(+) kg^{-1})	8.05	2.47	5.26
Exchangeable Mg (cmol(+) kg^{-1})	1.92	2.17	2.05
CEC (cmol(+) kg^{-1})	21.74	21.48	21.62

2.3. Experimental Design and Procedure

The experiment was conducted to determine the effects of tillage frequency, P fertilizer and weed control and their interactions on field pea for two years (2003 and 2004 main cropping seasons) at two locations. The experimental design was split plot with tillage treatments as main plots, and phosphorus fertilizer and weed control as sub-plots with three replications. The treatments included four levels of tillage frequency (four times tillage = April, May, early June and at planting; three times tillage = May, early June and at planting; twice tillage = May and at planting and one time tillage = at planting) and factorial combinations of four levels of P fertilizer (0, 10, 20 and 30 kg P ha^{-1}) and two levels of weeding (W_1 = no weeding, and W_2 = hand weeding once). Experimental fields were plowed by ox-drawn local plow. Phosphorus fertilizer was applied along with seeds as a single application in the form of triple super-phosphate. Experimental plots received blanket application of 20 kg N ha^{-1} as a starter dressing at planting in the form of urea.

An improved field pea cultivar (*Tegegnech*) was planted at the seed rate of 150 kg ha^{-1}. Sowing took place as per recommendation from 20 to 25 June at Welmera and the first week of July at Chelia each season. The crop rotation followed was field pea after food barley in the first year and after wheat in the second year at Welmera, and field pea after food barley both in the first and second years at Chelia. Plots receiving weed control treatment were weeded once by hand at the proper growth stage of plants.

2.4. Data Collection

Agronomic parameters collected included plant stand counts m^{-2} at complete emergence and harvest, plant height (average of ten plants), weed oven dry weight at weeding and harvesting of plants, number of pods per plant and seeds per pod (average of ten plants), total aboveground biomass, seed yield and thousand seed weight of field pea. To estimate total biomass and seed yield of field pea, sample size of 12 m^2 was harvested from each plot in November at Welmera and in December at Chelia. After threshing, the harvested materials, seeds were cleaned, weighed and adjusted to 10% moisture level. Total biomass and seed yield recorded on plot basis were converted to kg ha^{-1} for statistical analysis.

2.5. Statistical Analysis

The crop data were subjected to analysis of variance using the General Linear Model Procedure of SAS statistical package version 8.2 (SAS Institute, 2001). Data were combined over two years and two locations as the variances were homogenous. The total variability for each trait was quantified using pooled analysis of variance over years and locations. The least significant difference (LSD) test at 5% level of significance was used to compare the means. Pearson's correlation coefficients were also performed using the standard procedures from SAS program.

2.6. Economic Analysis

Data on land preparation and weeding (pair of oxen and labor person-days), fertilizer and seed prices were collected to investigate the economic feasibility of the treatments. Partial budget, dominance and marginal analyses were conducted. The average yield from the on-farm experimental plots was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. This is because experimental yields, even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments. The two years (2007and 2008) average price (ETB 5.55 kg^{-1}) of field pea was used to convert the adjusted yields into gross field benefits. The costs of tillage for a pair of oxen (ETB 50.00 per day), phosphate fertilizer (ETB 7.48 kg^{-1}) and weeding (ETB 10.00 per person-day) were also taken from the farmers' own practices in the study areas. For a treatment to be considered as a worthwhile option to farmers, the marginal rate of return (MRR) needed to be at least between 50 and 100% (CIMMYT, 1988). Researchers in other parts of the country suggested a MRR of 100% as realistic (Amanuel *et al.*, 1991). Thus, to make recommendations to farmers based on analysis, the minimum acceptable rate of return by the farmers was taken to be 100%.

3. Results and Discussion

3.1. Yield and Yield Components

On average, over the two experimental years, the data from this study revealed that the frequency of tillage, P fertilization and weed control treatments had significant effects on yield and yield components of field pea. Analysis of variance indicated that mean field pea seed yield, total plant biomass, number of pods per plant and seeds per pod highly significantly ($P < 0.001$) responded to the frequency of tillage, P fertilization and weed control (Table 2). Experimental locations and cropping seasons also significantly affected field pea growth, yield and weed biomass both at weeding and harvesting.

The mean field pea seed yield record was higher at Chelia (1799 kg ha^{-1}) than at Welmera (1387 kg ha^{-1}). While there was a significant difference between each of the tillage frequency, the highest mean seed yield of two years was recorded from plots plowed three times (Table 3). Plowing twice, three and four times, including the last pass for seed covering, increased mean seed yield of field pea by 38, 55 and 43%, respectively, compared to the control. Likewise, experimental findings at Holetta and Shamboo showed that repeated plowings before planting significantly increased seed yields of field pea and faba bean (Amare and Adamu, 1994; Tolera and Daba, 2004). Bellido *et al.* (2003) also reported that in three rainy years, pre-planting conventional tillage was found to be more productive than no tillage for faba bean production.

Harvest index was significantly different among P levels ($P < 0.001$) and between weed control treatments ($P < 0.01$) but not among tillage frequencies (Table 2). Similarly, thousand seeds weight, plant height and plant stand count at harvesting significantly ($P < 0.05$ to $P < 0.001$)) differed among tillage frequencies, P fertilization and between weed control treatments. Weed over dry weight at weeding was highly significantly ($P < 0.001$) affected by tillage frequency and significantly ($P < 0.05$) by P fertilization but not by weed control. Weed oven dry weight at harvesting also highly significantly ($P < 0.001$) responded to tillage frequency, P fertilization and weed control. Furthermore, total above ground biomass, number of pods per plant and plant height of field pea were highly significantly affected ($P < 0.001$) by the main effects of tillage, P fertilizer rate and weeding (Table 2). Accordingly, the highest mean total field pea biomass, number of pods per plant and plant height were recorded from three times tillage compared to other tillage frequencies (Tables 3 and 4). Similarly, weeding once and P fertilization at the rate of 20 kg P ha^{-1} gave the highest total above ground biomass yield and number of pods per plant among the treatments of the respective factors.

Yield and major yield components of field pea positively and significantly ($P < 0.001$) responded to P fertilizer. The application of P fertilizer at the rates of 10, 20 and 30 kg P ha^{-1} resulted in seed yield advantages of 30, 53 and 50%, respectively, compared to no P fertilizer treatment (Table 3). The results of the study indicated that the highest mean seed yield of field pea was obtained from the application of 20 kg P ha^{-1} although it did not differ significantly from the yield with 30 kg P ha^{-1}. Experimental findings on Nitisols and Alfisols of different locations of the country also showed that the application of phosphate fertilizer increased seed yields of field pea (Angaw and Asnakew, 1994; Getachew *et al.*, 2003; Amare *et al.*, 2005). The optimum dose of P for attaining an economic yield of field pea was found to be 20 kg ha^{-1}. Total biomass, harvest index, number of pods per plant and seeds per pod, plant stand count at harvesting, and weed biomass at weeding and at harvesting increased as P level increased up to 20 kg P ha^{-1} but decreased at 30 kg P ha^{-1} (Tables 3 and 4). In contrast, thousand seeds weight and plant height consistently increased as P rate increased.

The results of soil analysis were found to be sub-optimal for the production of field pea (Table 1). The soil pH and available P were below the optimum range. This had a direct relationship with the response of yield to applied phosphorus. In most cases, soils with pH less than 5.5 are deficient in available P, Ca and/or Mg (Cooke, 1986; Marschner, 1995; Getachew and Sommer, 2000). In such soils, the proportion of P fertilizer that could immediately be available to a crop becomes inadequate and residues of the fertilizer may be released very slowly (Sikora *et al.*, 1991). Legume species differ widely in their ability to grow in soils of low P status. Mahler *et al.* (1988) reported that, in terms of nutrient availability, field pea, lentil, chickpea and faba bean grow best in soils with pH values between 5.7 and 7.2 and require between 13 and 35 kg P ha^{-1} for adequate yields, which agrees with the findings of this study. When pulse crops are grown on soils with pH values of less than 5.6, they give low yields (Mahler *et al.*, 1988).

Table 2. Significance of mean squares for yield, yield components and agronomic traits of field pea analyzed for the effects of tillage frequency, P fertilizer rate and weeding at two locations for two years.

Source of variation	df	Yield, yield components and agronomic traits of field pea and weed biomass[a]									
		SY	BY	HI	TSW	SPP	PPP	PH	SC	WDM_1	WDM_2
Year (Y)	1	***	***	**	**	*	ns	**	**	**	***
Location (L)	1	*	***	**	**	ns	**	**	**	***	***
Y×L	1	***	***	***	***	ns	ns	ns	*	***	***
Tillage (T)	3	***	***	ns	*	**	***	***	**	***	***
Y×T	3	*	*	ns	ns	ns	ns	**	ns	*	***
L×T	3	*	***	ns	ns	ns	ns	ns	ns	***	***
Y×L×T	3	ns	***	ns	ns	ns	ns	ns	ns	***	***
Phosphorus (P)	3	***	***	***	***	***	***	***	**	*	***
Y×P	3	*	*	ns	ns	ns	ns	ns	*	*	ns
L×P	3	ns	*	*	ns	ns	ns	ns	ns	ns	ns
T×P	9	***	**	ns	ns	*	ns	*	*	***	***
Y×L×P	3	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y×T×P	9	ns	**	***	ns	*	ns	ns	ns	ns	***
L×T×P	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Y×L×T×P	12	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Weeding (W)	1	***	***	**	**	***	***	***	***	ns	***
Y×W	1	***	ns	**	ns	ns	ns	ns	ns	ns	***
L×W	1	***	***	ns	ns	ns	ns	*	ns	ns	***
T×W	3	**	*	*	ns	ns	ns	*	*	ns	***
Y×L×W	1	**	**	ns	ns	ns	ns	*	ns	ns	***
Y×T×W	3	ns	ns	*	ns	ns	ns	ns	ns	***	ns
L×T×W	3	ns	ns	ns	ns	ns	ns	ns	ns	**	***
Y×L×W	3	ns	ns	ns	ns	ns	ns	ns	ns	*	***
P×W	3	ns	ns	ns	ns	ns	***	ns	**	**	***
Y×P×W	3	ns	**	***	**	ns	ns	ns	ns	ns	***
L×P×W	3	ns		ns	ns	ns	ns	ns	ns	ns	***
T×P×W	9	*	**	*	ns	*	ns	*	*	*	***
Y×L×P×W	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Y×T×P×W	9	**	**	*	ns	ns	ns	ns	**	ns	*
Y×L×T×P×W	21	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
CV (%)		12.2	12.4	11.4	4.8	13.8	15.6	7.2	12.5	24.7	14.5

[a], ** and *** = Significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; ns = Not significant at $P > 0.05$; df = Degrees of freedom; SY = Seed yield; BY = Biomass yield; HI = Harvest index; TSW = Thousand seeds weight; SPP = Number of seeds per pod; PPP = Number of pods per plant; PH = Plant height; SC = Plant stand count at harvesting; WDM_1 = Weed dry mater at weeding; WDM_2 = Weed dry mater at harvesting; CV = Coefficient of variation.*

Weed control had a significant ($P < 0.001$) effect on seed yield, total biomass, number of pods per plant and seeds per pod, plant height, plant stand count and weed oven dry matter weight at harvesting and at $P < 0.01$ on harvest index and thousand seeds weight (Table 2). Nevertheless, weed oven dry matter weight at weeding was not significantly affected ($P > 0.05$) by weeding. Weeding once by hand at the proper growth stage of the plant resulted in mean seed yield advantage of 16% compared to the unweeded control treatment (Table 3). Similarly, a review by Rezene (1994) indicated that weed control operation at the proper growth stages of plants significantly increased seed yield and major yield components of field pea. Results of studies have shown that full-season weed competition caused yield reduction up to 15.3% in field pea (Rezene, 1986). The presence of weeds during the first 4, 7 and 10 weeks after sowing accounted for respective yield reduction of 0, 43.3 and 66.9% in field pea (Rezene, 1986). Knott and Halila (1988) also reported substantial yield reduction in food legumes due to weed competition. As depicted in the economic analysis, pre-planting tillage decreased to a great extent the amount of labor required to control weeds. The intensity and distribution of weeds decreased consistently as the frequency of tillage increased.

The critical period of weed competition in cool-season food legumes varies from 3 to 8 weeks after crop emergence. The extent to which the yield is reduced by weeds depends not only on the weed species and density, but also on the period for which the crop is exposed to weeds. The results of the study revealed that the weight of weed biomass at harvesting decreased to a great extent by 35% due to weeding compared to the weed biomass recorded in the unweeded conditions (Table 4). Weed biomass both at weeding and harvesting were higher at Chelia than at Welmera, in which field pea was grown after barley at Chelia, and after barley and wheat at Welmera. The plant groups most affected by tillage were the broadleaved weeds. The intensity of weed infestation was dependent not only on the soil tillage treatment but also on the herbicide level used on the preceding cereal crop (Rao, 2000). The higher the herbicide level, the lower the total dry matter production measured.

Table 3. Response of mean yield and yield components of field pea to the main effects of the factors.

Factor	Mean field pea yield and yield components [a]					
	SY (kg ha^{-1})[b]	BY (kg ha^{-1})	HI (%)	TSW (g)	PPP (No.)	SPP (No.)
Location:						
Welmera	1387b	3840b	36.0a	173b	6.5b	4.3
Chelia	1799a	5436a	34.0b	203a	6.8a	4.5
LSD (0.05)	39.16	114.22	0.77	1.88	0.22	Ns
Tillage frequency:						
Once	1187d	3449c	34	192a	5.6b	4.1b
Twice	1642c	4872b	34	187bc	6.9a	4.5a
Three times	1841a	5259a	35	188b	7.1a	4.5a
Four times	1702b	4974b	35	185c	6.9a	4.4a
LSD (0.05)	55.38	161.53	Ns	2.66	0.30	0.18
Phosphorus fertilization (kg ha^{-1}):						
0	1195c	3575c	33c	185c	5.4c	4.1b
10	1551b	4594b	34bc	187bc	6.7b	4.5a
20	1830a	5236a	36a	189ab	7.3a	4.6a
30	1796a	5149a	35ab	191a	7.1a	4.5a
LSD (0.05)	55.38	161.53	1.10	2.66	0.30	0.18
Weeding frequency:						
Unweeded	1474b	4369b	34.0b	190a	6.2b	4.2b
Once weeded	1712a	4908a	35.0a	186b	7.1a	4.6a
LSD (0.05)	39.16	114.22	0.77	1.88	0.22	0.13

[a]*Means within a column of the same factor followed by the same letter(s) are not significantly different at P < 0.05.*
[b]*SY = Seed yield; BY = Biomass yield; HI = Harvest index; TSW = Thousand seeds weight; PPP = Pods per plant; SPP = Seeds per pod; ns = Not significant at P > 0.05.*

Table 4. Response of some agronomic traits of field pea and weed biomass to the main effects of the factors.

Factor [d]	Plant height (cm)	Stand count m^{-2}	WDM$_1$ (g m^{-2})[e]	WDM$_2$ (g m^{-2})
Location:				
Welmera	107b	50b	41b	39b
Chelia	111a	53a	57a	61a
LSD (0.05)	1.41	1.29	2.56	1.68
Tillage frequency:				
Once	102c	47b	82a	108a
Twice	110b	51a	48b	43b
Three times	113a	53a	34c	23c
Four times	112ab	52a	32c	24c
LSD (0.05)	2.00	1.82	3.62	2.38
Phosphorus fertilization (kg ha^{-1}):				
0	99c	49b	46b	48b
10	111b	52a	49ab	48b
20	113ab	53a	51a	51a
30	114a	53a	50a	51a
LSD (0.05)	2.00	1.82	3.62	2.38
Weeding frequency:				
Unweeded	107b	50b	48	60a
Once weeded	112a	53a	50	39b
LSD (0.05)	1.41	1.29	ns	1.68

[d]*Means within a column of the same factor followed by the same letters are not statistically different at P > 0.05.*
[e]*WDM$_1$ = Weed dry matter at weeding; WDM$_2$ = Weed dry matter at harvesting; ns = Not significant at P > 0.05.*

The combined analysis of variance over the two cropping seasons showed that there were significant (P < 0.05; P < 0.01 and P < 0.001) year by location (Y×L), tillage by P fertilization (T×P), location by weeding (L×W), tillage by weeding (T×W), tillage by P fertilization and weeding (T×P×W), and year by tillage, P fertilization and weeding (Y×T×P×W) interactions for mean field pea seed yield, total biomass and weed biomass at harvesting (Table 2).

The seed yield of field pea obtained from the control (once tillage and no P) treatment was significantly (P < 0.05) lower compared to yields obtained from any of the remaining combinations of tillage frequency and P fertilizer rates (Table 5). Twice and three times tillage frequency brought about seed yield increments of 1181 and 1229 kg ha^{-1} at 20 kg P ha^{-1} compared to field pea seed yield obtained from once tillage and no P application with yield advantages of 149 and 155%, respectively. Similarly, sowing field pea at the second and third tillage frequencies with 20 kg P ha^{-1} and weeded once condition resulted in yield increases of 1419 and 1617 kg ha^{-1}, respectively, compared to once tillage, no P treatment and unweeded conditions (Table 6). The yield increments due to these treatments were 203 and 232%, respectively, compared to the control that is planting with the first pass of ox-drawn implement and with no P application and unweeded condition. In general, the highest mean seed yield (2314 kg ha^{-1}) of the two years was recorded from three times tillage, application of 20 kg P ha^{-1} and weeding once by hand. Likewise, Getachew *et al.* (2005) reported that the highest faba bean seed yield for the tillage and weed control interaction was obtained from three times tillage and weeding once by hand.

Table 5. Interaction effects of tillage frequency and P fertilization on mean field pea seed yield (kg ha^{-1}).

Tillage frequency	Phosphorus fertilization (kg ha^{-1})			
	0	10	20	30
Once	794	1190	1376	1389
Twice	1153	1533	1975	1908
Three times	1449	1840	2023	2052
Four times	1383	1641	1947	1836
LSD (0.05)	126.60			

Seed yield was significantly positively correlated with total biomass, number of pods per plant, plant height, number of seeds per pod, thousand seeds weight and plant stand count at harvesting (r = 0.93***, 0.54***, 0.54**, 0.41**, 0.37** and 0.34**, respectively) (Table 7). Total plant biomass and number of pods per plant were strongly correlated with seed yield, which indicates that high total aboveground biomass and number of pods per plant are essential for high seed yield production.

Table 6. Interaction effects of tillage, P fertilizer and weeding on mean field pea seed yield (kg ha^{-1}).

Tillage Frequency	P (kg ha^{-1})	Weeding	
		Unweeded	Weeded once
Once	0	697	892
Once	10	1141	1239
Once	20	1288	1465
Once	30	1267	1511
Twice	0	1122	1184
Twice	10	1347	1720
Twice	20	1834	2116
Twice	30	1808	2007
Three times	0	1295	1604
Three times	10	1697	1983
Three times	20	1732	2314
Three times	30	1901	2202
Four times	0	1291	1476
Four times	10	1589	1693
Four times	20	1879	2014
Four times	30	1699	1972
LSD (0.05)		179.10	

Table 7. Coefficients of correlation (r) among yield and agronomic parameters of field pea for mean values of two locations and two cropping seasons.

Character^{f}	SY	BY	HI	TSW	SPP	PPP	PH
SC	0.34**	0.31**	-0.05ns	0.26*	0.24*	-0.004ns	-0.02ns
PH	0.54**	0.53**	0.02ns	-0.09ns	0.42**	0.73***	
PPP	0.54**	0.52**	0.05ns	-0.08ns	0.25*		
SPP	0.41**	0.42**	-0.05ns	0.03ns			
TSW	0.37**	0.45**	-0.27**				
HI	0.06ns	-0.27*					
BY	0.93***						

, ** and * = Significant at P < 0.05, P < 0.01 and P < 0.001, respectively; ns = Not significant at P > 0.05; SY = Seed yield; BY = Biomass yield; HI = Harvest index; TSW = Thousand seeds weight; SPP = Number of seeds per pod; PPP = Number of pods per plant; PH = Plant height; SC = Plant stand count at harvesting.*

3.2. Economic Analysis

Economic analysis was conducted for tillage frequency, P fertilizer and weed control experiments taking mean seed yields of two years. As farmers attempt to evaluate the economic benefits of shifts in practice, partial budget analysis was done to identify the rewarding treatments. It is one of the concerns of the farmers to find options of field pea management that can provide better economic advantages. The farmers produce field pea without application of inorganic fertilizer, planting with the first pass and without weed control. These practices cannot, however, enable the farmers to produce as high a yield as possible and to earn the highest number of net benefits as possible. To fill this gap, 32 different management options were compared on farmers' fields to select the best options that can bring the greatest economic advantages.

According to net benefit analysis, positive net benefits ranging from 3179.85 to 9832.65 Ethiopian Birr (ETB) were obtained from producing field pea on a hectare of land (Table 8). The option with three times tillage, application of 20 kg P ha^{-1} and weeding once by hand gave the highest net benefit of 9832.65 ETB. Farmers' practice of once tillage, no fertilizer application and no weeding gave the lowest yield and net benefit of 3179.85 ETB ha^{-1}. Out of the total 32 treatments considered for economic analysis, 21 of them were dominated, indicating that the value of the increase in yields due to these treatments is not enough to compensate for the increase for costs. Hence, no farmer would choose treatments that incur additional costs. The dominated treatments were, therefore, eliminated from further economic analysis.

In the end, marginal analysis was conducted for the non-dominated eleven treatments, including the control treatment. In order to make recommendations to farmers based on analysis, the minimum acceptable rate of return by the farmers was assumed to be 100% for this experiment (Amanuel *et al.*, 1991). This implies that the farmers will not be willing to change their traditional practice of once tillage, no inorganic fertilizer and no weeding unless they get a minimum of 100% rate of return. If the minimum rate of return is below 100%, the change from one treatment to another will not be acceptable.

According to the results of the marginal analysis, the treatment with three times tillage, application of 20 kg P ha^{-1} and weeding once was identified to be the best option with a marginal rate of return of 423%, well above the minimum acceptable rate of return of 100% (Table 9). From this treatment, a marginal benefit of 804.00 ETB ha^{-1} was obtained from investing an extra 190.00 ETB ha^{-1}. Seven other treatments have also given a marginal rate of return well above the minimum rate of return (100%), but lower than the rate of return obtained from a treatment with a MRR of 423%. Nonetheless, they can be used as options for farmers with different income levels, in as far as they give a better rate of return than the traditional (control) practice. Therefore, the farmers can get the highest rate of return if they follow an improved agronomic practice with three times tillage, application of 20 kg P ha^{-1} and weeding once by hand for the production of field pea.

Table 8. Net benefit analysis results of field pea production as influenced by tillage, P fertilizer and weed control pooled over the two (Chelia and Welmera) locations.

Treatment[c]	Mean yield (kg ha^{-1})	Adjusted yield-10% (kg ha^{-1})	Gross benefit (ETB ha^{-1})	Costs that vary (ETB ha^{-1})				Net benefit (ETB ha^{-1})
				Tillage	P (kg ha^{-1})	Weeding	Total cost	
T1P1W1	697	627	3479.85	300	0	0	300	3179.85
T1P1W2	892	803	4456.65	300	0	370	670	3786.65
T1P2W1	1141	1027	5699.85	300	374	0	674	5025.85
T1P2W2	1239	1115	6188.25	300	374	370	1044	5144.25
T1P3W1	1288	1159	6432.45	300	748	0	1048	5384.45
T1P3W2	1465	1318	7314.90	300	748	370	1418	5896.90
T1P4W1	1267	1140	6327.00	300	1072	0	1372	4955.00
T1P4W2	1511	1360	7542.45	300	1072	370	1742	5800.45
T2P1W1	1122	1010	5605.50	500	0	0	500	5105.50
T2P1W2	1184	1066	5916.30	500	0	290	790	5126.30
T2P2W1	1347	1212	6726.60	500	374	0	874	5852.60
T2P2W2	1720	1548	8591.40	500	374	290	1164	7427.40
T2P3W1	1834	1651	9157.50	500	748	0	1248	7909.50
T2P3W2	2116	1904	10567.20	500	748	290	1538	9029.20
T2P4W1	1808	1627	9029.85	500	1072	0	1572	7457.85
T2P4W2	2007	1806	10023.30	500	1072	290	1862	8161.30
T3P1W1	1295	1165	6465.75	700	0	0	700	5765.75
T3P1W2	1604	1444	8014.20	700	0	280	980	7034.20
T3P2W1	1697	1527	8474.85	700	374	0	1074	7400.85
T3P2W2	1983	1785	9906.75	700	374	280	1354	8552.75
T3P3W1	1732	1559	8652.45	700	748	0	1448	7204.45
T3P3W2	2314	2083	11560.65	700	748	280	1728	9832.65
T3P4W1	1901	1711	9496.05	700	1072	0	1772	7724.05
T3P4W2	2202	1982	11000.10	700	1072	280	2052	8948.10
T4P1W1	1291	1162	6449.10	900	0	0	900	5549.10
T4P1W2	1476	1328	7370.40	900	0	220	1120	6250.40
T4P2W1	1589	1430	7936.50	900	374	0	1274	6662.50
T4P2W2	1693	1524	8458.2	900	374	220	1494	6964.20
T4P3W1	1879	1691	9385.05	900	748	0	1648	7737.05
T4P3W2	2014	1813	10062.15	900	748	220	1868	8194.15
T4P4W1	1699	1529	8485.95	900	1072	0	1972	6513.95
T4P4W2	1972	1775	9851.25	900	1072	220	2192	7659.25

[c]T1 = Control; T2 = Twice tillage; T3 = Three times tillage; T4 = Four times tillage; P1 = No P fertilizer; P2 = 10 kg P ha^{-1}; P3 = 20 kg P ha^{-1}; P4 = 30 kg P ha^{-1}; W1 = No weeding; W2 = Weeding once by hand.

Table 9. Marginal analysis of field pea response to tillage, P fertilizer and weed control for the mean of the two locations (Chelia and Welmera).

Treatment[f]	Adjusted yield - 10% (kg ha^{-1})	Total cost that vary (ETB ha^{-1})	Marginal cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Marginal benefit (ETB ha^{-1})	Marginal rate of return (%)
T1P1W1	627	300	-	3180.00	-	-
T2P1W1	1001	500	200	5105.00	1925.00	962
T3P1W1	1165	700	200	5766.00	661.00	330
T2P2W1	1212	874	174	5853.00	87.00	50
T3P1W2	1444	980	106	7034.00	1181.00	1114
T3P2W1	1527	1074	94	7400.00	366.00	389
T2P2W2	1548	1164	90	7427.00	27.00	30
T2P3W1	1651	1248	84	7909.00	482.00	574
T3P2W2	1785	1354	106	8553.00	644.00	607
T2P3W2	1904	1538	184	9029.00	476.00	259
T3P3W2	2083	1728	190	9833.00	804.00	423

[f]*T1 = Control; T2 = Twice tillage; T3 = Three times tillage; P1 = No P fertilizer; P2 = 10 kg P ha^{-1}; P3 = 20 kg P ha^{-1}; W1 = No weeding; W2 = Weeding once by hand.*

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