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Economic Evaluation of Tillage Systems and Nitrogen Fertilization for Maize Production in Western Ethiopia

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Abstract **– Experiments were conducted to determine agronomic and economic benefits of tillage systems and Nitrogen (N) fertilization for maize production in western Ethiopia. The experiments were conducted on-farmers' fields at five locations, namely, Bako, Shoboka, Tibe, Ijaji and Gudar. Three tillage systems viz. minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and conventional tillage (CT) and three N fertilization levels (69, 92 and 115 kg ha^{-1}) were combined in complete factorial arrangement. The experiment was laid out in randomized complete block design with three replications. Combined analysis over locations showed significant grain yield difference among tillage systems and N application rates ($P<0.05$), however, no significant yield difference was detected due to interaction between tillage system and N fertilization. The statistically significant treatments of this experiment were subjected to economic analysis using partial budget procedure with dominance, marginal and sensitivity analysis to determine tillage system and rate of N that would give acceptable returns at low risk to farmers. The partial budget analysis revealed that the highest net benefit was obtained from MTRR, followed by MTRV and then CT. Application of 92 kg ha^{-1} N is agronomically optimum and economically profitable for both MTRR and CT maize production in western Ethiopia. This recommendation remained robust and stable within a price variability range of 20%.**

Keywords **– Maize, Nitrogen Fertilizer, Partial Budget, Price Variability, Tillage System.**

I. Introduction

The health of Ethiopia's economy is highly influenced by the performance of the agricultural sector. Despite Ethiopia's long agricultural tradition and its importance in the national economy, the growth of the sector has remained low mainly due to a poor natural resource base and unfavorable socio-economic conditions. The poor natural resource base is even more limiting factor than the interlinked socio-economic conditions and nutrient mining of soils aggravates the situation and significantly contribute to the low economy of the country.

Careful management of cropping systems offers a possible reduction in the trade-off between maintaining profitability and reducing dependence on external inputs. Reduction of external inputs can be achieved inter alia by selecting tillage systems that coincide with residue retention [4], [7]. This approach usually resulted in the maintenance of long-term productivity and profitability of the land by gradual build-up of the soil fertility status through the internal cycling of nutrients [8], [12], [15].

The magnitude of economic returns for various tillage systems is the most important evidence of the viability and superiority of one tillage system over another. Acceptance of minimum tillage for maize production instead of conventional tillage depends more on its profitability than just the grain yields which realized. In general it is known that minimum tillage reduced costs of labor, fuel and machinery but increased costs of herbicides to maintain or increase grain yields [8]-[9].

The results of multi-year, multi-location production system trials must be subjected to economic analysis prior to issuing recommendations to farmers: while some sustainable cropping practices lead to greater short-term profitability and are more readily adopted by and promoted among farmers, other production practices may carry short-term costs in order to achieve greater sustainability and profitability in the long-term [10]. The acceptance of minimum tillage by Ethiopian farmers is low due to lack of knowledge on the economic benefits of the system. Therefore, this study was carried out with the objective of selecting economically profitable tillage system and appropriate rate of N fertilizer application to maize in western Ethiopia.

II. Materials and Methods

A. Experimental Sites

The trials were conducted at five locations, namely Bako, Shoboka, Tibe, Ijaji and Gudar in western Ethiopia. Bako is located at 09^0 01'N and 37^0 02'E, Shoboka at 09^{0}06' N and 37^{0}21'E, Tibe at 09^{0}29'N and 37^{0}32'E, Ijaji at 09^{0}43'N and 37^{0}47'E, and Gudar at 08^{0}09'N and 38^{0}08'E latitude and longitude, respectively. The altitude for Bako, Shoboka, Tibe, Ijaji and Gudar are 1650, 1695, 1730, 1820 and 2000 meter above sea level, respectively.

B. Field trial Layout

Field trials involving three tillage systems viz. minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and conventional tillage (CT) and three N fertilization levels (69, 92 and 115 kg N ha^{-1}) were combined in complete factorial arrangement. The experiment was laid out in randomized complete block design with three replications.

C. Economic Analysis

The economic evaluation was done on the grain yield data that was significantly affected by the tillage and N fertilization treatments to consolidate the statistical analysis thereon. This evaluation comprised of a partial budget with dominance, marginal and sensitivity analysis as described by [3]. The minimum acceptable rate of return was set at 100% and grain yield were adjusted downwards by 10% to minimize bias.

The input and output prices used in the economic evaluation were those prevailing during the period of the experiments. To estimate economic parameters, maize was valued at an average open market price of 1.02 Ethiopian Birr (EB) per kg grain and fertilizer was valued at a fixed official price of 5.80 EB per kg N. A wage rate of 4.5 EB per work-day and oxen rate of 18.0 EB per work-day were used. Round-up and lasso-atrazine were valued at 75 and 60 EB per L, respectively. Since maize residue has no monetary value in the study area, it was not considered in the economic evaluation.

D. Concepts used in Partial Budget Analysis

- Mean grain yield (kg ha^{-1}): Average yield of each treatment across sites.
- Gross field benefit (GFB) per ha: Product of real price of maize and the mean yield for each treatment.
- Total variable cost (TVC): Sum of costs of all variable inputs and management practices.
- Net benefit (NB) per ha: Difference between the GFB and the TVC.

The dominance analysis procedure was used to select potentially profitable treatments from the range that was tested. Treatments were ranked in order of ascending TVC from the lowest to the highest cost to eliminate those treatments costing more but producing a lower NB than the next lowest cost treatment. The selected and rejected treatments by using this technique are referred to as undominated and dominated treatments, respectively. For each pair of ranked undominated treatments, a percentage marginal rate of return (% MRR) was calculated. The % MRR between any pair of undominated treatments denotes the return per unit of investment in crop management practices or inputs expressed as percentage. The % MRR is given by the following Equation:

$$\% MRR = \frac{\Delta NB}{\Delta TVC} \times 100$$

Thus, a MRR of 100% implies a return of one Birr on every Birr of expenditure in the given variable inputs.

III. Results and Discussion

A. Effect of Tillage System and N Fertilization on Maize Grain Yield

The combined analysis of variance over locations revealed that both tillage system and N fertilizer application significantly ($P<0.05$) affected maize grain yield (Table 1). However, no significant yield difference was observed due to interaction between tillage system and N fertilization. On average, maize grain yield of MTRR was 400 and 705 kg ha-1 higher than that of MTRV and CT, resulting in yield increase of 6.6 and 12.2%, respectively. Application of N increased maize grain yield regardless of tillage system. In general, a progressive increase in maize grain yield was recorded with incremental levels of N applied. Further, grain yield response was more noticeable in the first than the second incremental level of N. Application of 92 kg ha^{-1} N was significantly superior to 69 kg ha-1 N, but on par with the 115 kg ha^{-1} N application, implying 92 kg ha^{-1} N application could be optimum level for both MTRR and CT systems. References [6] and [11] also recommended equal amount of N fertilizer application for optimum crop production for both MTRR and CT systems.

Table 1. Effect of tillage systems (minimum tillage with residue retention = MTRR, minimum tillage with residue removal - MTRV and conventional tillage = CT) and nitrogen fertilization on maize grain yield combined over locations.

N level	Tillage system (T)			
(kg ha^{-1})	MTRR	MTRV	CT	Mean
69	5953	5595	5210	5586
92	6513	6173	5868	6185
115	6953	6450	6227	6543
Mean	6473	6073	5768	
LSD(0.05)	T or N = 394	T x N = ns		

B. Economic Viability of Tillage Systems

The foregoing statistical results have indicated that significant effects of tillage system and N fertilization on maize grain yield in western Ethiopia. An economic analysis on the combined results using the partial budget technique is thus appropriate [3]. The result of the partial budget and the data used in the development of this partial budget is given in Table 2. Ranking of treatments in order of increasing TVC revealed that MTRR costs less than either MTRV or CT. It is clear that MTRR has considerably reduced cost of labor and oxen, but increased cost of herbicides compared to CT. The reduction of labor and oxen-power cost that coincides with minimum tillage can be attributed to less cultivation in preparing the seedbed and virtually no labor was used to control weeds. Consequently, the farmers would save some time for other farm activities. The highest NB was obtained with MTRR, followed by MTRV and then CT. The dominance analysis also indicated the superiority of MTRR to MTRV and CT. References [8] and [9] reported MTRR reduced cost of labor but increased cost of herbicides to maintain or increase grain yields.

Table 2. Partial budget with dominance and marginal analysis to establish the profitability of maize production with the three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage)

Tillage	Yield	GFB	Costs (EB ha^{-1})			TVC	NB	MRR
system	(kg ha^{-1})	(EB ha^{-1})	labor	oxen	herbicides	(EB ha^{-1})	(EB ha^{-1})	(%)
MTRR	5664	5199.6	71.5	133.2	525	729.7	4469.9	--
MTRV	5314	4878.3	125.8	111.6	525	762.4	4115.9	D
CT	5048	4634.1	264.15	590.4	0.0	854.6	3779.5	D

GFB = gross field benefit, EB = Ethiopian Birr, TVC = total variable cost, NB = net benefit, MRR = marginal rate of return and D = dominated treatment.

The input and output prices used in the economic analysis were those prevailing during the period of the experiment. Market prices are ever changing and as such a recalculation of the partial budget with a set of likely future prices is important to establish whether a tillage system is likely to remain stable and hence sustain acceptable returns for farmers despite price fluctuations. A sensitivity analysis was done therefore in which an increase in the field price of herbicides and a drop in the price of grain were assumed. The change in the prices of herbicides and grain is borne out of experience and represents a realistic fluctuation of liberal market conditions prevailing in the study area. Some of the considerations in projecting prices were increased maize supply due to increasing productivity and production, and increasing imported herbicide use due to adoption of conservation agriculture.

The dominance analysis selected MTRR as the undominated treatments, while MTRV and CT are dominated and now having been eliminated from the MRR calculation for giving a lower MRR than that of the subsequent change (Table 3). The sensitivity analysis indicated that MTRR remained the most economic tillage system when the maize price decreased by 20% and herbicide cost increased by 20%. However, with the concurrent changes in field prices of grain and herbicides the profitability of MTRR has become marginal. These results agree with [9] who showed that minimum tillage resulted in greater economic returns and lower production costs as compared with conventional tillage.

C. Economic viability of N levels for tillage

In this case the partial budget indicated that the highest TVC and NB were obtained at an application rate of 115 kg ha^{-1} N (Table 4). The dominance analysis showed that none of the N fertilization levels were dominant. However, the sensitivity analysis indicated that an application of 92 kg ha^{-1} N remained profitable, but the profitability of the application of 115 kg ha^{-1} N was well below the minimum acceptable rate and was therefore eliminated (Table 5). As a guideline the MRR of below 100% is considered low and unacceptable to farmers [3]. This is because such a return would not offset the cost of capital (interest) and other related transaction costs while still giving an attractive profit margin to serve as an incentive.

Table 3. Sensitivity analysis to establish the stability of maize production with the three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage)

Tillage system	GFB (EB ha^{-1})	TVC (EB ha^{-1})	NB (EB ha^{-1})	MRR (%)*
MTRR	4159.6	834.7	3324.9	--
MTRV	3902.6	867.4	3035.2	D
CT	3707.3	854.6	2852.7	D

*Denotes 20% increase in herbicide cost and 20% decrease in grain price. GFB = gross field benefit, TVC = total variable cost, NB = net benefit, MRR = marginal rate of return and D = dominated treatment.

Table 4. Partial budget with dominance and marginal analysis to compare the profitability of maize production with N fertilization

N level (kg ha-1)	TVC (EB ha-1)	NB (EB ha-1)	MRR (%)
69	400.2	4727.7	--
92	533.6	5144.2	312.2
115	667.0	5339.5	146.4

TVC = total variable cost, EB = Ethiopian Birr, NB = net benefit, MRR = marginal rate of return

Table 5. Sensitivity analysis to establish the stability of maize production with N fertilization

N levels (kg ha^{-1})	TVC (EB ha^{-1})	NB (EB ha^{-1})	MRR (%)*
69	480.2	3622.1	--
92	640.3	3901.9	174.8
115	800.4	4004.8	64.2

*Denotes 20% increase fertilizer N cost, and 20% decrease in grain price.

The MTRR plays an important role in the dynamic processes governing maize production and profitability on account of enhanced soil fertility. It is possible that with properly designed tillage practices viz. MTRR to alleviate soil related constraints in achieving potential maize productivity [1]-[2], [13]-[14]. However, improperly designed tillage practices (MTRV and CT) can set in motion a wide range of degradative processes like accelerated erosion, depletion of soil organic matter and fertility, deterioration in soil structure, disruption in cycles of nitrogen, phosphorus and other nutrients [5]. Hence, MTRR can be successfully and profitably introduced in the study area when it coincides with fertilization of at 92 kg N ha^{-1}. The replacement of CT with MTRR should contribute to sustainable maize production in western Ethiopia.

IV. Conclusion

The combined analysis over locations showed that tillage systems and N fertilizer rates had significantly ($P<0.05$) affected maize grain yield. However, interaction between tillage system and N application was non-significant on the grain yield. The partial budget analysis revealed that the highest net benefit was obtained from MTRR, followed by MTRV and then CT. The MTRR would still be the most economical tillage system when the maize price decreases by 20% and the herbicide cost increases by 20%. Application of 92 kg ha^{-1} N is agronomically optimum and economically feasible for maize production under MTRR and CT in western Ethiopia. Sensitivity analysis also indicated that application of 92 kg ha^{-1} N remained robust within a price variability range of 20%. However, with the concurrent changes in field prices of maize and herbicides, the profitability of this rate becomes marginal.

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