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# Farmers' Knowledge Helps Develop Site Specific Fertilizer Rate Recommendations, Central Highlands of Ethiopia

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**Abstract:** Soil testing is an important tool for preparing site specific fertilizer recommendations, but it has not been used by smallholder peasant farmers in Ethiopia and has not been profitable for many farmers in developed countries. The objective of this study was to use farmers' knowledge of soil fertility classification so as to develop technically and economically affordable site specific fertilizer rate recommendations. Factorial combinations of four levels of N (0, 46, 92 and 138 kg N $ha^{-1}$) and three levels of P (0, 20 and 40 kg P $ha^{-1}$) were tested in RCBD of four replications at each of relatively fertile and infertile black soil types determined by farmers in each year of 2005 and 2006. Soil sample analyses results and significantly ($p<0.05$) different crop response interactions of soil fertility types with NP fertilizers levels confirmed that the use of farmers' knowledge for defining soil fertility levels could help develop technically and economically affordable fertilizer rate recommendations specific to soil type fertility levels, agro-ecologies and production systems of Ethiopia. Thus application of $N_{101}P_{10}$ (200/50 of Urea/DAP) and $N_{130.5}P_{30}$ (225/150 of Urea/DAP) kg $ha^{-1}$ is recommended for bread wheat production on relatively fertile and infertile black soils, respectively, of the test location.

**Key words:** Black soil · Bread wheat · Farmers' knowledge · Site specific · Soil fertility · Trend analyses

## INTRODUCTION

It is well established fact that crop response and use efficiency to fertilizer application is significantly influenced by rate and time of application, weed control levels, level of soil organic matter, soil type, soil drainage conditions (in waterlogged areas), moisture conservation (in moisture deficit areas), unbalanced fertilizer application, variable weather conditions, diseases and insect pests and soil biological conditions [1]. With all these variations, fertilizer application in Ethiopia is still highly skewed to blanket recommendations ever since its inception in the late 1960s [2-4]. Moreover, farmers do not often go along with the recommended practices but follow practices they can afford, often half the recommended rate. On the other hand, the most severe soil degradation in the Ethiopian highlands due to crop mining, water and wind erosion is calling for immediate intervention. The average annual soil loss from croplands is estimated at 42 t $ha^{-1}$ [5] and that is about six times the rate of soil formation in some of the Ethiopian highlands [6]. Studies between 1993 and 1995 in Africa also show that Ethiopia was among the countries with the highest average soil nutrient depletion rate of more than 60 kg $ha^{-1}$ NPK nutrient annually [7], the major contributing factors being lack of adequate chemical fertilizer input, limited return of organic residues and manure and high biomass removal, erosion and leaching rates. Biofuel from wood, dung, crop residues and charcoal in 1998/99 constituted over 94% of the energy consumption of Ethiopia [8]. This is an indication that the trend has not yet been reversed and has direct implication on soil fertility depletion and erosion as such important organic residues are not returning to the soil. Under such alarming scenario, it is imperative to go for quick win solutions such as development of site specific chemical fertilizer recommendation scheme that is affordable and easy to practice by smallholder farmers of Ethiopia.

Soil testing is an important tool for preparing site specific fertilizer recommendations, but it has not been used by smallholder peasant farmers in Ethiopia and has not been profitable for many farmers in developed

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countries such as the United States of America. A review report [9] revealed that although crop consulting firms, soil testing laboratories and universities in the United States of America have provided fertilizer recommendations for decades based explicitly on soil tests, the implementation rate by the producers was typically under 30%; the major reason being the expected gains to using soil testing for many producers are insufficient to cover expected costs associated with it. The full impact of soil testing service in actual farming has not been visible in India having 514 (including 133 mobile) soil testing laboratories with capacity of analyzing 6.82 million soil samples per annum [10]. Reliable soil test results depend on proper soil sampling and sample processing procedures and proper soil analysis techniques, which all are the common deficiencies in Ethiopia. Moreover, agriculture in Ethiopia is a smallholder peasant based (accounting 95.8% of crop production) subsistence activity with the national average crop land holding size of 0.96 ha per household, the household size being 5.32 persons [11]. The worst thing is about 34% of holders have a crop land holding size of less than 0.51 ha that would be difficult to lead even subsistence life with the average productivity of 1866, 1133 and 631 kg $ha^{-1}$ grain yield for cereal, pulses and oil crops, respectively [11]. The cost implication of such small landholding size constituted of many parcels managed differently also discourages the use of chemical fertilizer inputs [12]. Similar experience was also reported in Nigeria [13]. The recent study on the number of parcels per land holding of a household in the central highlands of Ethiopia was found to be 4 on the average [14]. Thus a long time effort to promote chemical fertilizer input for crop production did not go far beyond the application of about 16 kg $ha^{-1}$ in NP nutrient form, as averaged over all crop lands in 2010/11 *meher* cropping season of Ethiopia [11]. Therefore, it would be additional cost and impractical to administer soil test based recommendations in such fragmented landholding and subsistence peasant farming systems.

Many participatory research works in Ethiopia proved that peasant farmers can classify soils according to their fertility status, productivity, color and texture that could be valuable inputs for site specific soil fertility management [15-17]. A research report from Ghana also indicated that peasant farmers have their own set of parameters which they use to determine the fertility of their soils without consultation with agriculture extension agents or soil research stations [18]. Farmers' classification of soils also showed good correlation with soil chemical and physical analysis and agronomic performance in upland rice production system of northern Laos [19]. Therefore, it is time to use indigenous knowledge of peasant farmers in Ethiopia to develop site specific chemical fertilizer recommendation until income and skill of farmers, easy access and affordability allows to use soil test based options that require well established system of administering soil sample collection, processing, reliable and standardized analysis. Thus the objective of this study was to use farmers' knowledge of soil fertility classification so as to develop technically and economically affordable site specific NP fertilizer rate recommendations for bread wheat production on the highland black soils of central Ethiopia.

## MATERIALS AND METHODS

**Study Area:** The experiment was conducted on farmers' fields in the central highlands of Ethiopia, near Debre Birhan town, about 130 km to the northeast of Addis Ababa on the way to Dessie. The geographical coordinates of the area in which the testing sites were selected: 9° 42' and 9° 45' latitude north and 39° 35' and 39° 39' longitude east. It is in the agro-ecology of $SM_2$ (tepid to cool sub moist). The altitude ranges from 2840 to 2943m asl with the annual rainfall of about 966mm as averaged over 20 years data of the nearby weather station at Debre Birhan Agricultural Research Center. The major soil type is black (*tikur mererie*), Vertisol, with the associated waterlogging problem.

**Experimental Sites Selection and Management Practices:** The land distribution undertaken in 1997 and 1998 by the Amhara Regional State also used farmers' knowledge to classify land in terms of fertility and productivity level. This information was used to select the relatively fertile and relatively infertile (hereafter referred to as fertile and infertile, respectively) sites for running the experiment. Additional confirmation was also made by asking at least five purposely selected knowledgeable farmers residing in the area. In this way, sites representing fertile and infertile black soil were selected in each of 2005 and 2006 experimental years. Five core soil samples to the depth of 0-20cm for each site were composited into one so as to determine some relevant soil physical and chemical parameters in each year (Table 1) and rating of measured

Table 1: Ratings of laboratory analysis results of soil types to the depth of 0-20cm as averaged over two sites for each soil type

| Soil properties | Fertile black soil | Rating | Infertile black soil | Rating |
|---|---|---|---|---|
| $p^H$ (1:2.5 soil to water ratio) | 7.02 | | 7.73 | |
| Organic C (%) | 1.47 | Medium | 0.90 | Low |
| Total N (%) | 0.15 | Medium | 0.09 | Low |
| Available P (ppm) | 9.08 | Medium | 2.92 | Low |
| Available K (ppm) | 152.39 | Medium | 103.47 | Low |
| Texture class | Clay | | Clay | |
| Sand (%) | 12 | | 11 | |
| Clay (%) | 64 | | 62 | |
| Silt (%) | 24 | | 27 | |

Note: methods used for determining soil properties:

- *Walkley-Black for organic carbon*
- *Olsen for available P*
- *Kjeldahal for total N*
- *Ammonium acetate for available K*
- *Hydrometer for texture*

parameters was done as given by Agriculture and Fisheries of the Netherlands [20]. Two plowings with oxen drawn local ard plow with sharp metal tip, *maresha,* were done from early June to mid July depending on the onset of rainfall, weed emergence pattern and sowing schedule. Broad beds and furrows (each 80cm bed spaced at 40cm drainage furrow) were made at sowing in 29-31 July of 2005 and in 29 June to 3 July of 2006 so as to drain excess soil water. Bread wheat variety HAR1899 at the seed rate of 150 kg $ha^{-1}$ was used. Two hand weedings were done: the first at tillering and the second just before booting stage of wheat. Harvesting close to the soil surface in 15-30 December was done on each net plot area of 9.6$m^2$so as to estimate yield per hectare.

**Design and Treatments:** Factorial combinations of four levels of N (0, 46, 92 and 138 kg N $ha^{-1}$) and three levels of P (0, 20 and 40 kg P $ha^{-1}$) were tested in RCBD of four replications at each site. The source of P fertilizer when applied alone was TSP, otherwise the source was DAP when P was applied together with N levels. Urea and DAP were the sources of N fertilizer. All DAP or TSP and half of urea fertilizers were applied at sowing according to the treatment levels assigned to each plot. Consequently, the remaining half of urea fertilizer was applied at tillering stage soon after weeding on the same date.

**Data Analyses:** ANOVA and trend analyses using orthogonal contrast and stepwise multiple regression procedures [21, 22] were done using SAS software Version 8.1 of 1999-2000, SAS Institute Inc., Cary, NC, USA. Probability level of 5% was used for entering and retaining each term in stepwise multiple regression analysis. Heterogeneity of error variances was encountered mainly due to the nature of treatments like $N_0P_0$, $N_0P_{10}$, $N_0P_{20}$ and $N_0P_{40}$ kg $ha^{-1}$ that were extremely low yielding. Because none of the four soil type by year environments had a coefficient of variation larger than 20%, being in the range of 7.45 to 12.95% for grain and straw yields, all are included in the combined analyses over years and soil types [21]. Combined analysis in General Linear Model Procedure was run in which only N, P and interaction of N by P are fixed while all other sources of variation are random [21, 23]. The combined analysis revealed that soil fertility types significantly ($P<0.05$) affected the response of grain and straw yields of bread wheat to applied NP fertilizers. Consequently, analysis of variance was done separately for each soil fertility type across years.

Economic analysis was done following procedures in the economics workbook of CIMMYT [24]. From the fitted curves equations within the range of the tested NP levels of the experiment, predicted grain and straw yields of 64 combinations of NP levels were generated. The predicted yields were adjusted downward by 10%. The farm gate prices of the respective 8.00 and 2.08 Ethiopian Birr (ETB) $kg^{-1}$ of grain and straw yields of wheat in December 2011; and the respective 11.50 and 9.50 ETB $kg^{-1}$ for DAP and urea fertilizers (including interest and transport costs) in June 2011 were used for analyses. According to the author's observation in the last three years period (2008 to 2011), the farm gate prices of input (DAP and Urea fertilizers) and output (wheat grain and straw) on the average have escalated by 63.5 and 51.7%, respectively. Thus the assumption for sensitivity analysis was to keep output prices constant at 8.00 and 2.08 ETB $kg^{-1}$ of wheat grain and straw, respectively, as of December 2011 while input price increases by 63.5% in the future.

## RESULTS AND DISCUSSIONS

**Grain Yield:** Only linear and quadratic components of grain yield response to nitrogen levels significantly (p<0.01) varied between years on infertile black soil whereas year had no significant effect on the response pattern of either N or P levels on fertile black soil (Table 2). Plotting the interaction of year with N levels on infertile black soil shows that at N levels higher than 46 kg $ha^{-1}$, grain yield response maintained linearity in 2006 while it changed to quadratic in 2005 (Figure 1). This variation in year effect was largely due to far apart sowing dates followed in the trial period. Sowing on 29 July 2005 depressed productivity as compared to sowing on 3 July 2006 on infertile black soil. Even though the interaction of year with N or P was not significant on the fertile black soil, early sowing in 03 July 2006 significantly (p<0.01) depressed grain yield (Figure 1). The recommended practice on black soils in general is to sow early while the soil is moist [25, 26] that usually happens in the first decade of July. However, farmers are not willing to practice this recommendation [27] even for relatively light black soils let alone for heavy black soils. These observations led to sowing date (four sowing dates with seven days interval starting from 10 July) trials in 2007 and 2008 on relatively light and heavy black soils that resulted in the respective quadratic and positively linear grain yield responses of bread wheat [Unpublished data of the author], supporting the farmers' practice.

The five terms ($N_{-linear}$, $P_{-linear}$, $N_{-linear}$ x $P_{-linear}$, $N_{-linear}$ x $P_{-quadratic}$ and $N_{-quadratic}$ x $P_{-quadratic}$) selected as significant (P<0.05) by orthogonal contrast analysis (Table 2) explained 99.2% of the total variation in grain yield on infertile black soil. But the stepwise multiple regressions selected only three terms ($N_{-linear}$, $N_{-linear}$ x $P_{-linear}$ and $N_{-quadratic}$ x $P_{-quadratic}$) explaining 99% of the total variation in grain yield. Thus terms selected by stepwise multiple regression were used so as to avoid redundant terms ($P_{-linear}$ and $N_{-linear}$ x $P_{-quadratic}$) in predicting yield. No interaction component of the NP response trend was significant on the fertile black soil (Table 2). In the orthogonal contrast analysis of variance only $N_{-linear}$, $N_{-quadratic}$ and $P_{-linear}$ components of the response

Table 2: Orthogonal contrast analysis of variance summary for the effect of N and P fertilizers and years on grain and straw yields of bread wheat

| | | Infertile black soil | | Fertile black soil | |
|---|---|---|---|---|---|
| Source of variation | DF | Mean squares of grain yield | Mean squares of straw yield | Mean squares of grain yield | Mean squares of straw yield |
| Year (Y) | 1 | 2226809 | 1598826* | 3538944** | 2089780 |
| $N_L$ ($N_{-linear}$) | 1 | 49547673** | 73773617** | 30363092** | 56777890*** |
| $N_Q$ ($N_{-qudratic}$) | 1 | 431078 | 3508673** | 1677459** | 1228085 |
| $N_C$ ($N_{-cubic}$) | 1 | 15289 | 23843 | 95824 | 123778 |
| ($Y_1$ vs $Y_2$) x $N_L$ | 1 | 2145751** | 56312 | 12241 | 1014760 |
| ($Y_1$ vs $Y_2$) x $N_Q$ | 1 | 254101** | 147032 | 57 | 12195 |
| ($Y_1$ vs $Y_2$) x $N_C$ | 1 | 7046 | 1481 | 62153 | 342401 |
| $P_L$ ($P_{-linear}$) | 1 | 5372545* | 7408604** | 1326816* | 1475314 |
| $P_Q$ ($P_{-quadratic}$) | 1 | 226669 | 713578* | 217958 | 70265 |
| ($Y_1$ vs $Y_2$) x $P_L$ | 1 | 35579 | 30233 | 7678 | 260993 |
| ($Y_1$ vs $Y_2$) x $P_Q$ | 1 | 88967 | 15212 | 103928 | 91919 |
| $N_L$ x $P_L$ | 1 | 2474737** | 5187475** | 5192 | 200450 |
| $N_L$ x $P_Q$ | 1 | 952245** | 1151281** | 11337 | 130830 |
| $N_Q$ x $P_L$ | 1 | 20844 | 13082 | 48675 | 196138 |
| $N_Q$ x $P_Q$ | 1 | 234850** | 82129 | 94652 | 181118 |
| $N_C$ x $P_L$ | 1 | 32866 | 223080* | 24728 | 158287 |
| $N_C$ x $P_Q$ | 1 | 8730 | 206 | 506 | 87230 |
| ($Y_1$ vs $Y_2$) x ($N_L$ x $P_L$) | 1 | 1995 | 15056 | 10753 | 586617* |
| ($Y_1$ vs $Y_2$) x ($N_L$ x $P_Q$) | 1 | 9444 | 4425 | 207006 | 899 |
| ($Y_1$ vs $Y_2$) x ($N_Q$ x $P_L$) | 1 | 29 | 21134 | 14250 | 217040 |
| ($Y_1$ vs $Y_2$) x ($N_Q$ x $P_Q$) | 1 | 78449 | 128599 | 82212 | 160372 |
| ($Y_1$ vs $Y_2$) x ($N_C$ x $P_L$) | 1 | 9713 | 8873 | 133457 | 723236* |
| ($Y_1$ vs $Y_2$) x ($N_C$ x $P_Q$) | 1 | 689 | 34596 | 36890 | 160089 |

**Significant at P<0.05; **significant at P<0.01; ***significant at P<0.001; DF = degree of freedom;*
*$Y_1$ = 2005; $Y_2$ = 2006.*

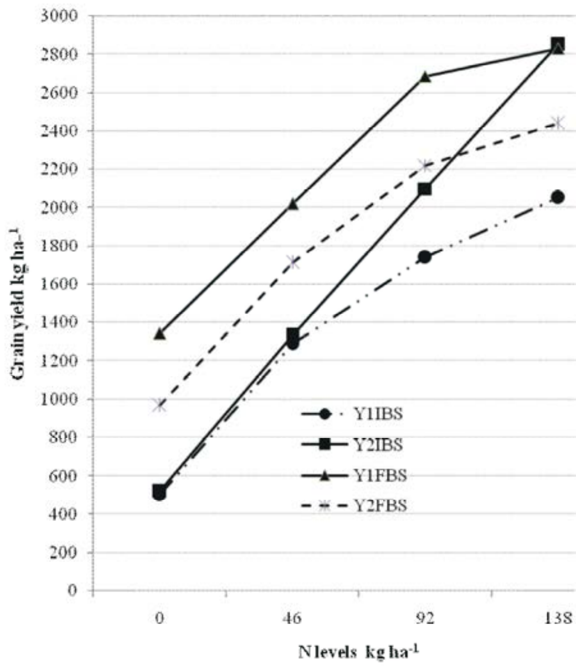


Fig. 1: Grain yield response of bread wheat to N levels as affected by soil fertility types and years
Y1IBS is year 2005 on infertile black soil; Y2IBS is year 2006 on infertile black soil; Y1FBS is year 2005 on fertile black soil; Y2FBS is year 2006 on fertile black soil

trend were significant, explaining about 98% of the total variation in grain yield. However, in the selected equation generated by stepwise multiple regression, $N_{\text{-quadratic}}$ was replaced by $N_{\text{-cubic}}$ and $P_{\text{-quadratic}}$ was added, explaining about 99% of the total variation in grain yield. In the stepwise regression analysis, not only the model fit but also each term in the predicted grain yield equation was significant ($p<0.05$). The response curve (Figure 2) clearly shows that each P level alone had little contribution to grain yield increment on both soil fertility types even though a positive trend was observed on fertile black soil that may probably be due to relatively higher soil organic carbon, total nitrogen and available potassium (Table 1). Earlier research works elsewhere in Ethiopia also showed that even though most Ethiopian Vertisols are deficient in P, field crop responses to applied P fertilizer alone was little even under improved drainage conditions [28, 29]. As shown in Figure 2, grain yield increased with increasing N levels when applied alone, but the yield levels were always less than those obtained from the respective N levels applied together with their matching P levels on both soil fertility types. For example, grain yields of $N_{46}P_0$, $N_{92}P_0$ and $N_{138}P_0$ kg ha$^{-1}$ were about 90%, 75% and 63% of the respective grain yields of $N_{46}P_{20}$, $N_{92}P_{20}$ and $N_{138}P_{20}$ kg ha$^{-1}$ on infertile black soil. This trend also shows that application of phosphorus is critically required for N rates

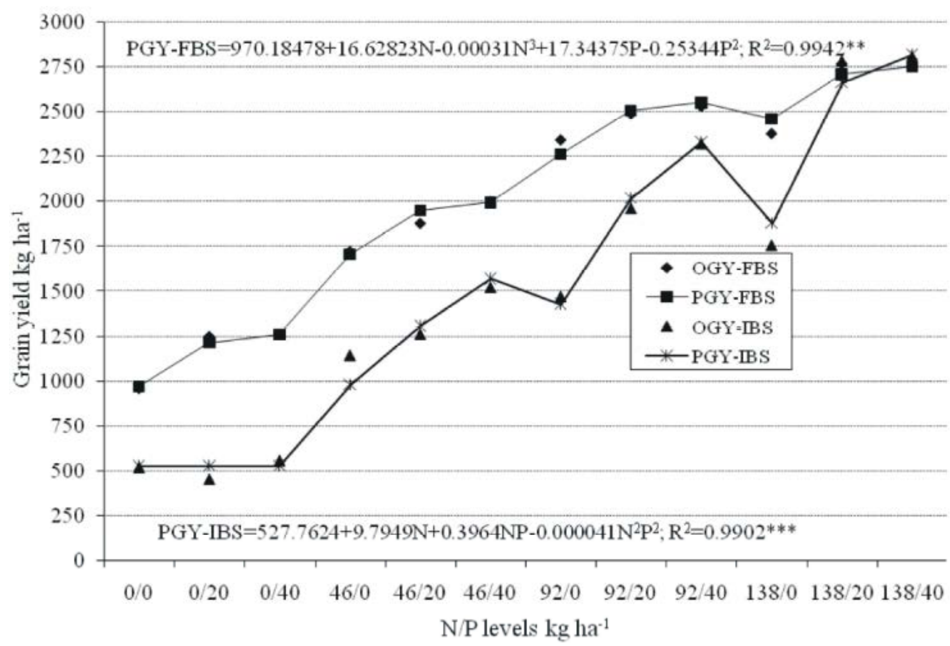


Fig. 2: Grain yield response of bread wheat to N/P fertilizers on fertile and infertile black soils, averaged over two years. OGY-FBS is observed grain yield on fertile black soil; PGY-FBS is predicted grain yield on fertile black soil; OGY-IBS is observed grain yield on infertile black soil; PGY-IBS is predicted grain yield on infertile black soil; **significant at p<0.01; ***significant at p<0.001

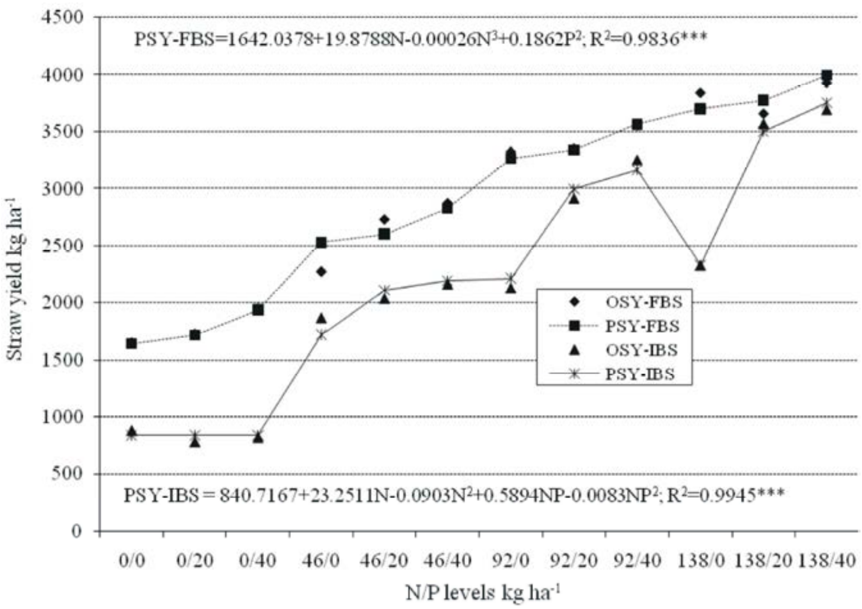


Fig. 3: Straw yield responce of bread wheat to N/P fertilizers levels on fertile and infertile black soils, averaged over two years.
OSY-FBS is observed straw yield on fertile black soil; PSY-FBS is predicted straw yield on fertile black soil; OSY-IBS is observed straw yield on infertile black soil; PSY-IBS is predicted straw yield on infertile black soil; ***significant at $p<0.001$

higher than 46 kg ha$^{-1}$ for infertile black soil and for N rates of 92-138 kg ha$^{-1}$ on fertile black soil. It has already been established elsewhere that crop utilization of P is significantly enhanced when the appropriate balance of nutrients like N is available; N enhances P uptake by increasing top and root growth, altering the plant metabolism and increasing the solubility and availability of P [30, 31]. Generally, rate of crop yield response to NP levels on infertile black soil was higher than that of fertile black soil (Figure 2) because of the low fertility status of the infertile black soil as indicated in Table 1. On the fertile black soil, grain yield increment obtained by increasing NP level from $N_{138}P_{20}$ to $N_{138}P_{40}$ kg ha$^{-1}$ was negligible. However, this may not necessarily indicate the attainment of plateau because grain yield might increase if N level is increased above 138 kg ha$^{-1}$. On the infertile black soil, grain yield increased with increasing NP levels.

**Straw Yield:** The same explanation given for grain yield also applies for significant interactions of year with either P or N levels (Table 1) on both soil fertility types. The seven significantly ($P<0.05$) contributing terms ($N_{-linear}$, $N_{-quadratic}$, $P_{-linear}$, $P_{-quadratic}$, $N_{-linear}$ x $P_{-linear}$, $N_{-linear}$ x $P_{-quadratic}$ and $N_{-cubic}$ x $P_{-linear}$) selected by the orthogonal contrast analysis on infertile black soil explained 99.7% of the total variation in straw yield (Table 1) as compared to the only four significant ($P<0.05$) terms ($N_{-linear}$, $N_{-quadratic}$, $N_{-linear}$ x $P_{-linear}$ and $N_{-linear}$ x $P_{-quadratic}$) selected by stepwise multiple regressions explaining 99.5% of the total variation (Figure 3). This is just to show that it was possible to avoid such redundant terms ($P_{-linear}$ and $P_{-quadratic}$) which are statistically significant but contributing little to the estimated curve fit. The response curve (Figure 3) clearly shows that the contribution to straw yield increment by each P level alone was very little while by that of each N level alone was generally larger. However, the effect of N levels was synergistically improved when it was applied together with P. For example, straw yields of $N_{46}P_0$, $N_{92}P_0$, and $N_{138}P_0$ kg ha$^{-1}$ were about 92%, 73% and 65% of the respective yield of $N_{46}P_{20}$, $N_{92}P_{20}$ and $N_{138}P_{20}$ kg ha$^{-1}$.

This trend also indicates that the need for P fertilizer application increases with increasing N levels.

On the fertile black soil, the orthogonal contrast trend analysis of variance on N, P and their interactions showed that only $N_{-linear}$ component of the response trend was significant ($P<0.0001$) explaining 93.7% of the total variability in straw yield while the contribution of either P levels alone or their interaction with N levels was not significant (Table 2). However, the stepwise multiple regression was able to detect, in addition to $N_{-linear}$, the significant contribution of $N_{-cubic}$ ($P=0.0116$) and $P_{-quadratic}$ ($P=0.0369$) that generated a response curve equation

Table 3: Summary of economic analyses values selected from 64 combinations of NP fertilizers levels on fertile and infertile black soils

| | Previous Recom. | Fertile black soil | | | Previous Recom. | Infertile black soil | |
|---|---|---|---|---|---|---|---|
| Urea/DAP (kg/ha) | 150/100 | 200/50 | 225/50 | 225/75 | 150/100 | 225/150 | 225/175 |
| Adjusted grain yield (kg/ha) | 2215 | 2235 | 2298 | 2366 | 1751 | 2459 | 2531 |
| Adjusted straw yield (kg/ha) | 2945 | 3056 | 3168 | 3227 | 2625 | 3303 | 3372 |
| Fertilizer cost (Birr/ha) | 2575 | 2475 | 2713 | 3000 | 2575 | 3863 | 4150 |
| Net return (Birr/ha) | 21269 | 21758 | 22264 | 22644 | 16897 | 22680 | 23108 |
| Marginal rate of return, MRR (%) | Dominated | 304 | 213 | 132 | 308 | 302 | 149 |
| Sensitivity analysis | | | | | | | |
| Cost of fertilizer at | | | | | | | |
| 63.5% increase in price | | 4047 | 4435 | 4905 | 4210 | 6315 | 6785 |
| Net return | | 20186 | 20542 | 20738 | 15262 | 20227 | 20472 |
| MRR (%) | | 147 | 92 | 42 | 150 | 146 | 52 |

Note: *One USD was on the average equivalent to about 17 ETB in the year 2011*

explaining 98.4% of the total variation in straw yield (Figure 3). This curve also showed that, unlike on the infertile black soil, P alone was increasing observed straw yields on the fertile black soil, that is the respective straw yields from $N_0P_0$, $N_0P_{20}$ and $N_0P_{40}$ kg $ha^{-1}$ were 1652, 1729 and 1951 kg $ha^{-1}$.

The probable reason for this positive trend of P levels when applied alone may be the enhancing effect of the relatively higher fertility status of the fertile black soil in total nitrogen, total organic carbon and available potassium (Table 1). The fertile black soil was higher yielder than the infertile black soil throughout the tested levels even though the gap was narrow at higher NP rates. The highest treatment level ($N_{138}P_{40}$ kg $ha^{-1}$) was the highest yielder on both soil fertility types (Figure 3) giving the observed straw yields of 3695 kg $ha^{-1}$ on infertile black soil and 3928 kg $ha^{-1}$ on fertile black soil. These trends also showed that straw yield plateau has not yet been attained on both soil fertility types.

**Economic Analyses:** Economic analyses, after 10% downward adjustment on the predicted grain and straw yields from the response curve fitted for each soil type, indicated that application of $N_{135}P_{35}$ (225/175 kg/ha of Urea/DAP) on infertile black soil and $N_{117}P_{15}$ (225/75 kg $ha^{-1}$ of Urea/DAP) on fertile black soil gave the highest respective net benefit of 23108 and 22644 ETB $ha^{-1}$ among the fertilizer levels with MRR values = 100% (Table 3). However, sensitivity analysis with the assumption of fertilizer price escalation by 63.5% rejected these two NP combinations giving MRR lower than 100% [25] that could be very risky for subsistent peasant farmers in the present market scenario that is difficult to predict. The previous blanket recommendation of applying $N_{87}P_{20}$ (150/100 kg $ha^{-1}$ of Urea/DAP) was dominated at the initial stage of economic analysis on fertile black soil while it gave 308% MRR and 16897 Birr/ha net benefit on infertile black soil, at which its MRR was also 150% in sensitivity analysis. Other NP combinations selected by sensitivity analysis for having MRR values = 100% and higher net benefit of 20186 and 20227 ETB $ha^{-1}$ on the respective fertile and infertile black soils are $N_{101}P_{10}$ (200/50 kg $ha^{-1}$ of Urea/DAP) and $N_{130.5}P_{30}$ (225/150 kg $ha^{-1}$ of Urea/DAP), respectively (Table 3). Therefore, application of 200/50 and 225/150 kg $ha^{-1}$ of Urea/DAP fertilizer is recommendable on fertile and infertile black soils, respectively. These specific recommendations also show that fertilizer requirements of these two soils are not only different in NP fertilizer rates per se but also in their ratios; giving N:P ratio of 4.35:1 on infertile black soil and 10.1:1 on fertile black soil. The relatively higher level of soil P on the fertile black soil (Table 1) demanded for more nitrogen fertilizer application than phosphorus. The overall results testify that site specific fertilizer recommendations are possible by using farmers' knowledge to classify soils according to their practical fertility levels in different soil types, agroecologies and production systems of Ethiopia. But specific soil tests can be made whenever soil nutrient imbalances are suspected to limit crop response to applied NP fertilizers. Otherwise, it would be very difficult and unaffordable to the smallholder subsistent peasant farmers of Ethiopia to use soil test based fertility management under the prevailing illiteracy, food insecurity, poor crop husbandry, fragmented landholding, inaccessible and few laboratories and grinding poverty scenarios.

## CONCLUSION AND RECOMMENDATIONS

Soil sample analyses results and significantly ($p<0.05$) different crop response interactions of soil fertility types with NP fertilizers levels confirmed that the use of farmers' knowledge for defining soil fertility levels could help develop technically and economically affordable fertilizer rate recommendations specific to soil fertility levels in each soil type, agro-ecology and production system. Thus application of $N_{101}P_{10}$ (200/50 of Urea/DAP) and $N_{130.5}P_{30}$ (225/150 of Urea/DAP) kg $ha^{-1}$ is recommended for bread wheat production on relatively fertile and infertile black soils, respectively, of the test location. These specific recommendations also show that fertilizer requirements of these two soil fertility types are not only different in NP fertilizer rates per se but also in their ratios; giving N:P ratio of about4:1 on infertile black soil and 10:1 on fertile black soil. Soil tests can be made whenever soil nutrient imbalances are suspected to limit crop response to applied NP fertilizers. Otherwise, it would be very difficult and unaffordable to the smallholder subsistent peasant farmers of Ethiopia to use soil test based fertility management under the prevailing illiteracy, food insecurity, poor crop husbandry, fragmented landholding, inaccessible and few laboratories and grinding poverty scenarios. Under the alarming soil degradation due to crop mining, water and air soil erosion and very low level of fertilizer application limited by economic and technical problems, it is time for Ethiopia to use farmers' knowledge and develop economically and technically affordable site specific fertilizer recommendations so as to enhance productivity and reduce soil degradation.

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## REFERENCES

1. Fageria, N.K., V.C. Baligar and C.A. Jones, 1997. Growth and Mineral Nutrition of Field Crops. Marcel Dekker, Inc., New York, USA.
2. Demeke, M., A. Said and T.S. Jayne, 1997. Promoting Fertilizer Use in Ethiopia: the Implications of Improving Grain Market Performance, Input Market Efficiency and Farm Management. Working Paper 5. Ministry of Economic Development and Cooperation, Addis Ababa, Ethiopia.
3. Demeke, M., V. Kelly, T.S. Jayne, A. Said, J.C. Le Vallee and H. Chen, 1998. Agricultural Market Performance and Determinants of Fertilizer Use in Ethiopia. Grain Market Research Project Working Paper 10. Ministry of Economic Development and Cooperation, Addis Ababa, Ethiopia.
4. Ministry of Agriculture and Rural Development, MoARD, 2009. Environment and Social Assessment Fertilizer Support Project (Project ID: P113156) Report. MoARD, Addis Ababa, Ethiopia.
5. Hurni, H., 1990. Degradation and Conservation of the Soil Resources in the Ethiopian Highlands. In African Mountains and Highlands: Problems and Prospectives, pp: 51-64.
6. Hurni, H., 1983. Soil formation rates in Ethiopia. Working Paper 2. Ethiopian Highlands Reclamation Studies, Addis Ababa, Ethiopia.
7. Henao, J. and C.A. Baanate, 1999. Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands in Africa. IFDC, Muscle Shoals, Alabama.
8. Gebreegziabher, Z., 2007. Household Fuel Consumption and Resource Use in Rural-Urban Ethiopia. PhD Thesis, Wageningen University, the Netherlands.
9. Kastens, T.L. and K.C. Dhuyvetter, 2005. Soil Sampling, Especially for N and P: Does it Pay? (with a consideration of other dynamic issues). web: www.agmanager.info
10. Tiwari, K.N., 2002. Fertilizer Recommendations: Need a Fresh Look. Fertilizer Knowledge No. 4. Potash and Phosphate Institute of Canada-India Program, Gurgaon.
11. Central Statistical Agency, CSA, 2011. Agricultural Sample Survey 2010/2011 Report on Land Utilization, Private Peasant Holdings, Meher Season. Statistical Bulletin 505. CSA, Addis Ababa, Ethiopia.

12. Negatu, W., 2005. Agricultural Technology, Farm Size and Household Food Security Status: Empirical Observation in South Wollo and Oromia zones, Amhara Region, Ethiopia. A paper presented on the BASIS/-CRSP workshop on Lessons Learnt about Poverty and Food Insecurity in South Wollo: Policy and Research Implications. Organized and sponsored by BASIS/IDR-CRSP, Ghion Hotel, Addis Ababa, 7-8 March, 2005.
13. Udoh, A.J. and E. Umoh, 2011. Fertilizer Use and Measures for Increased Sustainable Consumption by Peasant Farmers: Food Security Approach in Rural Nigeria. Journal of SAT Agricultural Research, 9: 1-8.
14. Tefera, M.M., 2009. Causes of Rural Household Food Insecurity: A Case from Kuyu District, Central Ethiopia. Journal of Sustainable Development in Africa, 11(4): 286-304.
15. Belachew, T. and Y. Abera, 2010. Assessment of Soil Fertility Status with Depth in Wheat Growing Highlands of Southeast Ethiopia. World J. Agric. Sci., 6(5): 525-531.
16. Corbeels, M., A. Shiferaw and M. Haile, 2000. Farmers' Knowledge of Soil Fertility and Local Management Strategies in Tigray, Ethiopia. Managing Africa's Soils, pp: 10.
17. Pound, B. and E. Jonfa, 2005. Soil Fertility Practices in Wolaita Zone, Southern Ethiopia: Learning from Farmers. Policy and Research Series 2. Farm Africa, London, UK.
18. Agyarko, K., E.K. Asiedu, I.K. Atubiga and S. Anane, 2011. Determination and Rstoration of Soil Fertility by Local Farmers:The Case of Techiman Municipality of Ghana. World J. Agric. Sci., 7(6): 667-671.
19. Saito, K., B. Linquist, B. Keobualapha, T. Shiraiwa and T. Horie, 2006. Farmers' Knowledge of Soils in Relation to Cropping Practices: A Case Study of Farmers in Upland Rice Based Slash-and-Burn Systems of Northern Laos. Geoderma, 136: 64-74.
20. Agriculture and Fisheries of the Netherlands, 1989. Agricultural Compendium for Rural Development in the Tropics and Subtropics. Third Edition. Elsevier Science Publishers, Amsterdam, the Netherlands.
21. Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. Second Edition. John Wiley and Sons, Inc., Singapore.
22. Petersen, R.G., 1977. Use and Misuse of Multiple Comparison Procedures. Agron. J., 69: 205-208.
23. Petersen, R.G., 1994. Agricultural Field Experiments: Design and Analysis. Marcel Dekker, Inc., New York.
24. International Maize and Wheat Improvement Center, CIMMYT, 1988. From Agronomic Data to Farmer Recommendations: An Economic Workbook, Mexico, D.F.: CIMMYT.
25. Asamenew, G., H. Beyene, A. Haile and W. Negatu, 1993. Technology Transfer and Validation. In Improved Management of Vertisols for Sustainable Crop-Livestock Production in the Ethiopian Highlands: Synthesis Report 1986-92. Technical Committee of the Joint Vertisol Project, Addis Ababa, Ethiopia, pp: 139-146.
26. Joint Vertisol Project, J.V.P., 2000. The Joint Vertisol Mnagement Project: Summary of Achievements and Lessons learnt. Addis Ababa, Ethiopia.
27. Pankhurst, A., 2001. Potential for and Constraints on the Use of Broad Bed Maker Technology in Ethiopia. In Advances in Vertisols Management in the Ethiopian Highlands. Proceedings of the International Symposium on Vertisols Management, 28 November to 1 December 2000, Debre Zeit, Ethiopia. EARO, Addis Ababa, Ethiopia, pp: 127-137.
28. Haque, I., M. Abebe, T. Mamo and A. Dibabe, 1993. Nutrient Management. In Improved Management of Vertisols for Sustainable Crop-Livestock Production in the Ethiopian Highlands, Synthesis report 1986-1992. Technical Committee of the Joint Vertisol/ Management Project, Addis Ababa, Ethiopia, pp: 51-75.
29. Woldeab, A., T. Mamo, M. Bekele and T. Ajema, 1991. Soil Fertility Management Studies on Wheat in Ethiopia. In Wheat Research in Ethiopia: A Historical Perspective. IAR/CIMMYT, Addis Ababa, Ethiopia, pp: 137-172.
30. FAO., 1999. Fertilizer Strategies. Revised version. FAO, Rome, Italy.
31. Tisdale, S.L., W.L. Nelson and J.D. Beaton, 1985. Soil Fertility and Fertilizers. 4th Edition, New-York, Macmillan Publishing Co.