Yield Gap Analysis for Maize-based Landuse System in Central Nepal

Abbadi Girmay Reda

Senior Researcher and Director General,
Tigay Agricultural Research Institute (TARI), POb: 492, Mekelle, Ethiopia,
Email: Abbadigirmayreda [AT] gmail.com

ABSTRACT— ***Maize is the main food crop in the hilly areas of Nepal. A Comparative Performance Analysis (CPA) study was undertaken to identify maize yield constraints and quantify their impacts on yield in Makuwanpur District (Central (Nepal). For 68 fields, yield ranged from 200 to 4900 kg/ha with a mean of 2020kg/ha, and a standard deviation of 1120kg/ha. Data on land and management aspects were collected during a field survey. Data acquisition methods included direct measurement/observation of biophysical aspects (recorded on relevee sheet), interviews of land users, visit to a nearby research station and extension offices. The dataset included land and management parameters. The production model identified a terrain unit (Upland plateau & Highland hills versus all others), a management parameter (Quantity of applied urea) and lodging as the three major yield constraints that explained 65% of the encountered yield variability. The impact of each identified constraint on yield (yield-gap of 1928 kg/ha) was 61%, 23 % and 16 %, respectively. Results of this CPA study were in line with the farmers` perception of constraints faced to explain differences between actual and expected yields. CPA was further explored to find significant interactions of urea applied with other land and management aspects to improve the predictive power of the earlier model. Use of specific constraint-management functional relationships enhances the standard CPA method and provides opportunities to identify by constraint specific management requirements. This method could have a wide range of application in the context of diverse agroecosystems and NRM constraints.***

Keywords— Landuse System, CPA, SLM, Quantified production function model, stepwise regression.

1. INTRODUCTION

General

Nepal is a mountainous country with more than two-thirds of the land area (about 85%) classified as mountains and hills. Agriculture is the major economic activity of the people. Rapid population growth has led to increasing pressure on the limited land resources, forcing the use of marginal land for agricultural purposes. Intensive use of marginal and slopping lands for grain production in hills has resulted in declining soil fertility, soil erosion and in an overall environmental deterioration (Regmi, 1993).

Agriculture in the hilly areas is traditionally based on crop/livestock mixed farming. Steep slopes are terraced and crops are grown under rainfed conditions. Under agricultural intensification and expansion into marginal lands, sustaining the soil fertility is a major challenge in the Nepalese hills. The soil system in the slopping areas is highly fragile and vulnerable to soil erosion and landslides (Brown, 1999).

Maize-based cropping systems are dominant in the hilly areas. Maize is grown as a single crop, intercropped with legumes (beans or soybeans) or relay-cropped with finger millet. In the hills, maize stands first in cropped area (Rajbhandari et al., 1997).

Problem Statement

Maize production is constrained by different biophysical, management and socio-economic factors. In Nepal, there is a lack of information on actual production constraints, on yield-gaps, and on how farmers perceive constraints and avoid risks. This study is done through Comparative Performance Analysis (CPA; de Bie, 2000) and aims at filling the gap for maize-based cropping systems in the hilly areas of Nepal. The farmers` situation is different and unique by plot. Yield – gap studies based on Comparative Performance Analysis of actual production situations aims at identifying and quantifying the land and land use aspects that are responsible for differences in production levels. Such studies are the basis for well-informed agricultural landuse planning scenarios, setting priorities for research and extension, and for improving the landuse system towards sustainable use. Analysing the impact of management options to reduce the impact of specific constraints, i.e., to base CPA on specific constraint-management relationships, can improve the predicting power of the model and improve the existing CPA approach. Such a study approach will enhance the methods of CPA for yield- gap analysis, quantified land evaluation (QLE) and sustainable land management (SLM).

Objectives

The general objective of the study is to identify through CPA all important yield constraints, to quantify their impacts on maize yields and to identify specific constraint –management relationships. That is :

1. To identify yield constraints and quantify the relative importance of each yield constraint to the overall yield gap.

    The hypothesis to test is:

    "Maize yield is a function of Land and Management Parameters"

    Yield = f (Land, Management)

2. To identify specific constraint –management relationships.

3. To quantify an improved production function that considers the specific management-constraint relationships.

2. CONCEPTS

Landuse Systems (LUS)

A Landuse system is defined as "A specific land use , practised during a known period of time on a known unit of land that is considered homogenous in land resources" (de Bie 2000). It is composed of two main elements: Land and land use. Land use purpose (s) and the operation sequence characterize land use. The context within which land use systems occur, defines the state of current land use system. Relevant aspects of landuse at the plot level are basically biophysical in nature.

Activities (operations) at plot level aim at modifying one or more aspects of land. Operations can be pre-planned or can be a remedial in nature depending on occurring dynamic land processes. An Operation Sequence is defined as "A series of operations on land, carried out by humans, in order to realize one or more set landuse purposes." (de Bie 2000). Adequate information on the operation sequence is a precondition for adequate analysis on the performance of the land use system, e.g. on productivity and sustainability. The biophysical aspects of landuse systems relate to the biophysical performance and include land characteristics that condition the productivity of land use. If information on the biophysical possibilities and constraints is known, it is likely to influence the land holder`s decisions. The general system diagram of a land use system (figure 1) illustrates the complex interaction of land and management in a landuse system. In this study, context aspects were not covered. Land characteristics and followed management practices in a specific area differ from field to field and from season to season. Yield constraints at field levels include biotic and abiotic factors. Biotic factors are weeds, pests and diseases. Abiotic factors are many, including terrain, soil characteristics, slope, and management aspect. Decisions on land use purposes and operations are made at the farm (holding) level and are conditioned by the goals and aspirations of the farmer, his resources, biophysical options, and the socio-economic-political environment. Interactions between the various landuse systems on a farm complicate the decision making process. Land use reflects the outcome of this decision making process. In this study, only the landuse system specific part to maize production is studied.

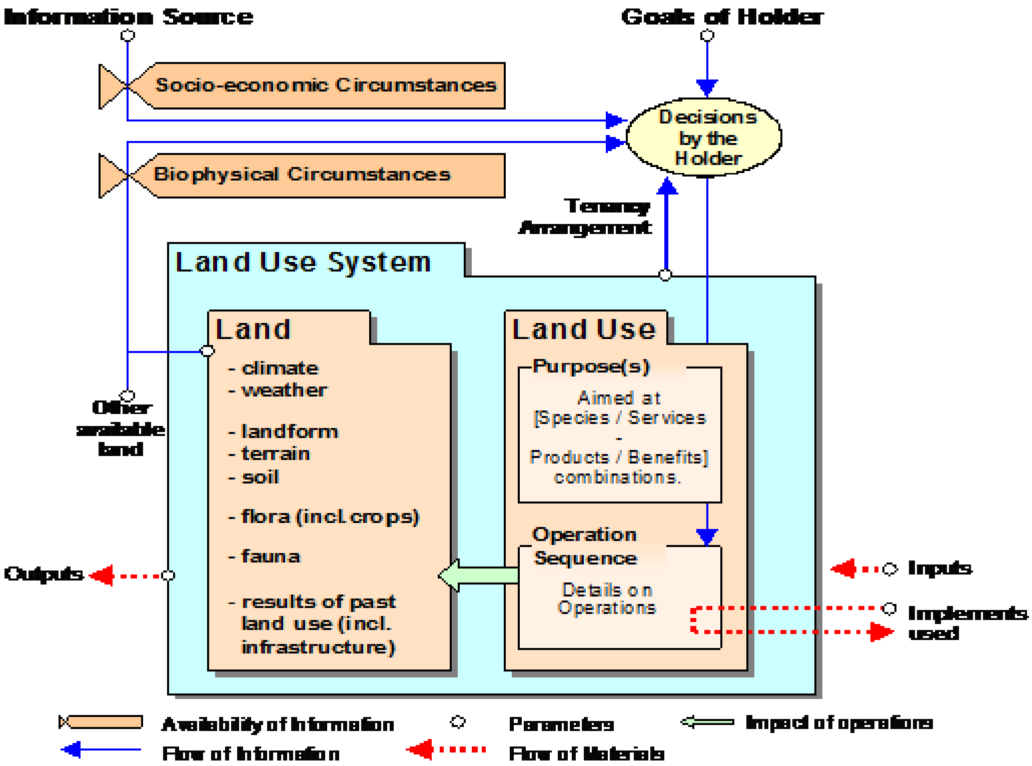

Figure 1. Landuse System (LUS): Outline of elements and context (de Bie , 2000).

2.2. Yield-gaps

Technologies developed at research stations didn't take sufficient account of technical and socio-economic constraints that confront small farmers (Fresco 1984). Farmers are inclined to accept lower yields at lower risk levels. This results in a considerable "yield-gap" between actual yield and yields possible with improved technologies. De Datta (1981) defined "yield-gap" as the difference between yields on research stations and the actual yield on farms. Factors that are responsible for yield-gaps are called yield constraints. The conceptual model of the yield gap includes four main gaps, i.e. between calculated potential yield and maximum yield from research station, technical ceiling yield, economic ceiling yield, and actual farmers` yield. Both biophysical and socio-economic factors are thus taken into account (Fresco 1984). Types of yield-gaps and their dominant causes are presented in fig.2.

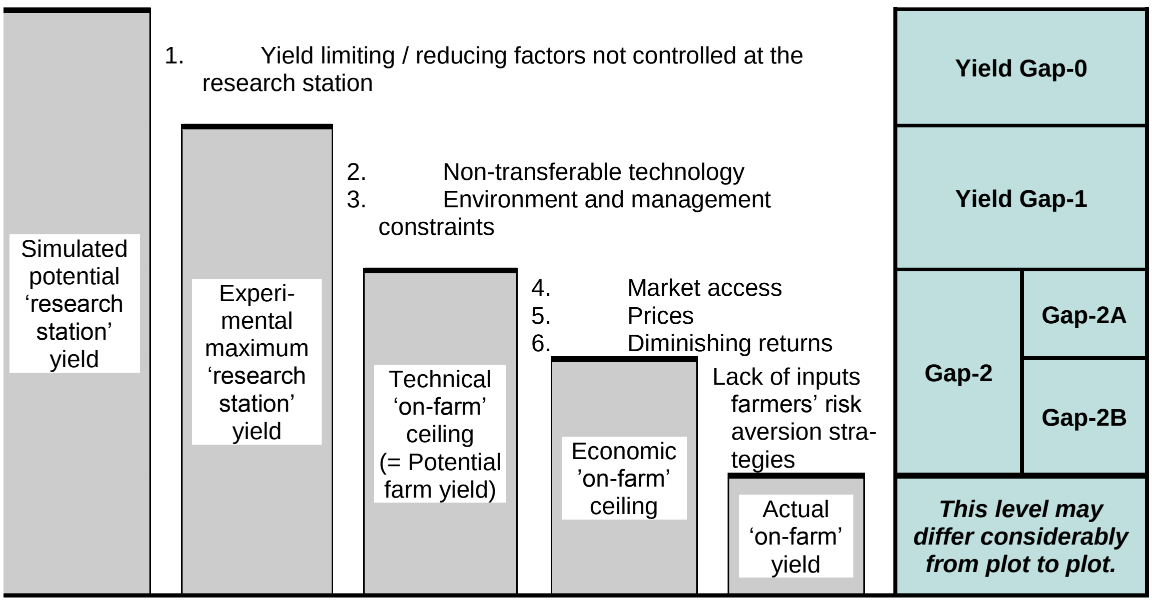

Figure 2. Partial yield-gaps and their dominant constraints (de Bie, 2000).

Comparative Performance Analysis (CPA) : Principles & Applications

Comparative Performance Analysis (CPA) considers actual on-farm situations assuming that land users operate at several technological levels. Successful CPA studies must focus on a particular land use class and the land use systems surveyed must reflect the entire prevailing range of environmental conditions and all types and levels of technologies practised (environmental conditions and management aspects as they occur in the study area). The key feature of CPA is to relate differences in land and land use at a number of sites to differences in system performance (de Bie 2000). CPA can be characterized by two basic descriptive functions, i.e. for quantifying yield (production):

Production = f (land, land use)

For quantifying environmental impacts by the land use system:

Impact = f (land, land use)

Empirical production functions obtained through CPA can not be extrapolated beyond actually surveyed production situations.

The CPA Study Method

CPA study methods include the following components:

Pre-field work
There is a need to define data requirement. Only relevant aspects of land use must be collected.

In this phase, images and topomaps are used to identify the study area. Images are processed and classified to generate a priori-land cover/use classes. A Sampling scheme is developed by stratifying sample points on a classified land cover/use map.

Field work
Data are collected through direct measurement/observation by the surveyor and through interviewing the land user. Interviews can be based on questionnaires or checklists. During the first days of a survey, the sample scheme and image map must be reviewed and the prepared relevee sheet and questionnaire/checklists tested for suitability, feasibility, and comprehensiveness.

The accessibility of pre-selected sample sites must be taken into account. Surveyors must also calibrate their methodologies (standardize measurement techniques and observations/interview methods).

Post-field work
Post-fieldwork includes data management and data analysis. Coding and structuring of collected data in tables (spreadsheets) and /or databases is required before starting analysis. Categorical parameters are "normalized" and changed into ratio variables containing only "1" or "0" (true or false) values as required for regression analysis. Data are screened through descriptive statistics and tested for correlation among variables.

Regression models are used to identify yield constraints, to quantify their impacts on yield and to predict yield. Descriptive models such as regression equations are fit to quantify system response to environmental factors.

.Step-wise forward linear multiple regression is applied to derive the model. Yield is considered as a function of land and management parameters (Moore and McCabe1998).

3. MATERIALS AND METHODS

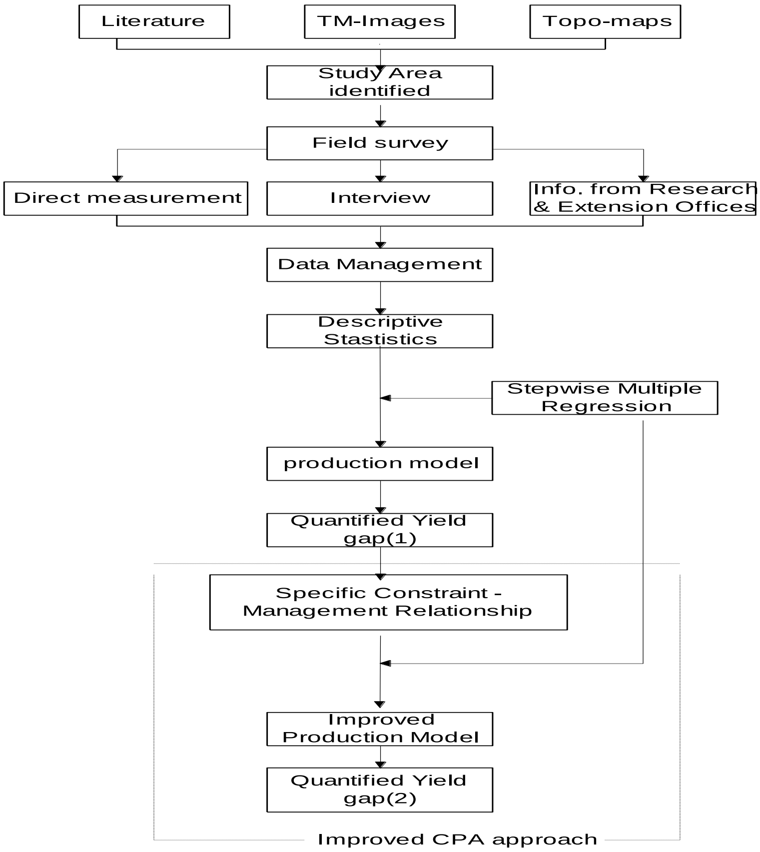

Figure 3. Flow chart of the research approach

3.1. The Study Area

Makuwanpur district (figure 4) is located between 84^0 41`-$84^0$ 35`E longitude and 27^0 21`-$27^0$ 40` N latitude. The district is surrounded by Sindhuli & Kavrepalanchok in the east, Chitwan in the west.

Figure 4. The Study Area

Table 1. Land & management parameters

Land parameters	Management parameters
♦ Slope (%), Top soil PH ♦ Top soil texture, Terrain ♦ Erosion hazard, Water logging ♦ Soil workability, Aspect and ♦ Soil & water conservation infrastructure	♦ Land preparation, Planting ♦ Weed control, Manure & Fertilizer application ♦ Pest & disease control, Harvesting ♦ Yield data (Kg/ha) , and ♦ Farmers` perception of constraints

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

Yield

Yield data recorded in different local measurement units were converted into Kg/ha. Yield was the dependent (response) variable. To fulfil the assumptions of regression analysis that dependent variables should be normal (Moore and McCabe1998), the distribution of yield data was checked. Yield data ranged from 200 to 4900 kg/ha with a mean of 2020kg/ha and standard deviation of 1120 for 68 fields.

Land Parameters and Yield

Land parameters included in this study were: slope within the field and in the area, terrain units (position in the landscape), top soil texture, topsoil pH, sign of erosion, waterlogging and soil workability.

Slope

Most of the study area consisted of steep slopes except the upland plateau and flood plain, which are relatively flat areas. Slopes reached upto 140%. Terraced farming occurs in the hills.

Slope had a significant negative effect on yield. Slope in the area had a more negative effect on yield than slope in the field; this might be due to the application of traditional terracing practices. Regression analysis to test the effect of slope in the area on yield gave an Adj. R^2 of 18.8% and p-value < 0.001).

Yield versus Terrain units

Six terrain units were identified in the study area: Highland hills (HH), Mid hills (MH), Foothills (FH), Upland plateau (UP), River terraces (RT) and Floodplains (FP). One way ANOVA is used for comparing several population means. ANOVA tests the null hypothesis that the population means are all equal and the alternate hypothesis is that they are not all equal (Moore & McCabe 1998). If p-value is greater than the specified probability level we have no evidence to reject the null hypothesis that the populations have equal means.

Table 2. Terrain units and Yield

Terrain unit	No. of observation (N)	Mean yield (kg/ha)	ANOVA
UP	16	3406.3 *	P< 0.001
FP	9	1858.8	df=67
HH	16	1184.4 *	
MH	9	1431.9)	
RT	9	1905.5	
FH	9	1908.3	

Means followed by * are significantly different from other means.

The null hypothesis that mean yields are equal among the different terrain units was rejected (p < 0.001) at 5% probability level and we had evidence that not all of the means are equal (table5). Least Significance Difference (LSD=

t*S.E) indicates which mean is significantly different from the other means (Moore & McCabe 1998). Upland plateau (**UP)** and Highland Hills (**HH**) were significantly (*) different from all others at Alpha=0.05. Upland plateau significantly increased yield while highland hills did significantly reduce yield.

Top soil texture

Texture of the topsoil was determined in the field by "Thein's feel method". Five textural classes were identified as sandy, sandy loam, silty loam, clay and clay loam. These textural classes were further grouped into three broad categories as "coarse" (sandy & sandy loam), "medium"(silty loam) and "fine" (clay & clay loam). ANOVA indicated that there was no significant yield difference among these three textural classes (P= 0.820). Soil texture influences the movement of water and nutrients through the profile, and also affects root growth. Textural class affects water-holding capacity.

50 out of the total 68 sample points had fine (clay, clayloam) and medium (siltyloam) textural classes that are optimal texture requirements for maize (FAO 1978) but textural class did not significantly affect yield.

Top Soil pH

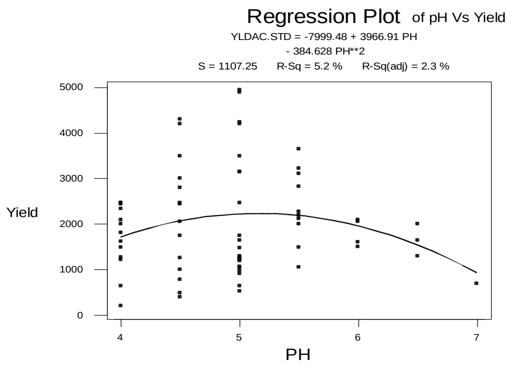

Figure 5. PH and yield

50 out of the 68 sites had a pH between 4 to 5 (acidic). The effect of pH on yield was analysed through regression. The curve estimation resulted in a quadratic regression (figure 5).

The result of this regression equation showed that yield was not significantly affected by pH (Adj. R^2 = 2.3%, P= 0.178). The optimal pH requirement of maize is in the pH range of 5.2 to 8.2 (FAO 1978, Lafitte 1994).

pH 5 was correlated with upland plateau(r =0.380 ,p =0.001)and gave higher yield than other pH –values. PH 6.5 was correlated with flood plain and hence lower yield (r =0.337 ,p =0.005). pH 4 had correlation with foot hills (r=0.437, p <0.001).

Table 6 shows the relation between textural classes and pH. Coarse texture had a significant correlation with pH range 6 to 7 (r=0.284, P = 0.019) and fine texture with pH range 5 to 5.5 (r=0.253, p=0.038). Texture class coarse was correlated with flood plain (r = 0.402, p = 0.001).

Table 3. Count of texture class by pH

Texture Class	**pH Ranges**		
	4-4.5	**5-5.5**	**6-7**
Coarse	**7**	**6**	**5**
Medium	**9**	**6**	**2**
Fine	**11**	**21**	**1**

Waterlogging
According to farmers waterlogging was one of the production problems. It was rated as “no problem”, “low” and “medium”. No significant yield difference among the three waterlogging classes was found (P =0.351).

Maize is very sensitive to waterlogging at the early growth stage. Later in the crop cycle, waterlogging can be tolerated for a period of upto one week, though yields will reduce. Waterlogging can result in nitrogen deficiency (Lafitte 1994).

Waterlogging Class (low) was correlated with foot hills **(**r= 0.242, p=0.047) and waterlogging (medium) was correlated with flood plain (r= 0.551 ,p <0.001).Texture class coarse was correlated with flood plain (r = 0.402, p = 0.001).

Erosion Signs
The presence of erosion signs (presence of pre-rills, rills, and gullies) in the field and its surrounding was recorded. The effect of presence versus absence of such signs was analysed. The result of t-test showed that presence of erosion signs significantly reduced yield (P < 0.001).

Soil Workability
Soil workability problems as they were perceived by farmers (as “problematic” and “easy”) were analysed for their effect on yield. There was no significant yield difference between the two classes of soil workability (t-test, P = 0.295).

Management parameters and Yield
Farmers apply different management practices (operations) to get reasonable yield from their land and they operate at different technological levels. Data collected on operation sequences followed by farmers of the study area (land preparation through harvesting) were analysed. The data included all levels of technologies practised in the area and production levels achieved to maximize the chance to identify all major yield constraints. The data include: land preparation, planting, weed control, pest and disease control, manure and chemical fertilizer application, and harvesting.

Land Preparation
The primary purposes of land preparation (tillage) prior to planting are to create a soil structure favourable for crop growth, to incorporate crop residues, and to control weeds (Lafitte 1994).In the study area, land preparation was carried out from January to late March. Time of land preparation (days after 1/1/2000), frequency of ploughing and main power source were analysed for their effect on yield. Time of first ploughing had no significant effect on yield (Adj.R^2 = 0.0%, P = 0.675**).** Time of Second ploughing had no significant effect on yield (Adj. R^2= 2.0 %, P =0.186)

Frequency of ploughing (three ploughings)
There was no significant yield difference among the ploughing frequency (df = 67, F=1.54,p= 0.222).

Main power source for ploughing
Farmers in the upland plateau (16x) used tractor while farmers in other terrain units (52x) used oxen for ploughing their land.

Two-sample t-test showed that there was significant yield difference between the two main power sources **(**P < 0.001**).** Tractor ploughing significantly increased yield, though the effect would also be attributed to differences between terrain units.

Method of Planting
Method of planting, row versus broadcasting, were compared for their effect on yield. ANOVA shows that there was significant yield difference between the two methods. Broadcasting significantly increased yield (P < 0.001). The method used strongly correlated with seed rates used.

Seed Rate
Farmers use different seed rates for various reasons. The recommended rate for the area is 35 kg/ha. Farmers applied high seed rates when planting through broadcasting. Farmers compensate germination loss, loss due to insect pest attack and losses due to different factors through high seed rates. Seed rates significantly increased yield **(**Adj. R^2 = 25.8 %, p < 0.001**).** An increase of 1kg seed increased yield by 21 kg.

Manure and Fertilizer Application
Farmyard manure is applied as a source of organic fertilizer; chemical fertilizers as an inorganic source. Three mineral elements are required in relatively large quantities: nitrogen, phosphorus, and potassium. These are the nutrients that most frequently limit maize production. Yields can often be reduced by 10-30 % by deficiencies of major nutrients (Lafitte 1994).

The major causes of nutrient deficiencies include:

- Non or insufficient application of fertilizer.
- Fertilizer applied is lost to leaching, run off, or volatilization.

- Untimely fertilizer application or when the crop is already stunted due to factors such as inadequate weed control

- Waterlogging.

- Extreme Soil pH levels.

Farm yard Manure Application
96 % of all farmers applied manure on their fields during land preparation. The source of manure was cow dung and poultry waste. Farmers applied large quantities of manure. The effect of quantity of manure applied on yields was analysed. Farmyard manure was not expected to result in yield variability in because almost all fields received similar treatment. Curve estimation of the effect of manure on yield resulted in a quadratic regression; it was not significant (Adj. R^2=0.0%, P=0.679).

Fertilizer Application (Quantity, method and time of fertilizer application)

Basal Application of DAP and Complexeal (NPK-Compound)

Farmers apply DAP (Di-Ammnium Phosphate) and Complexeal at planting. Of the total 68 farmers, 8 applied DAP and 9 applied Complexeal, respectively. Complexeal is manufactured in India and has a composition of 20 N, 20 P2O5 and 20 K_2O. The majority of the farmers did not apply chemical fertilizers at planting as they are applying large quantities of manure. Basal application of DAP and Complexeal had no significant impact on yield variability (Adj. R^2 =0.0%, P= 0.404).

Urea Application as top dressing :

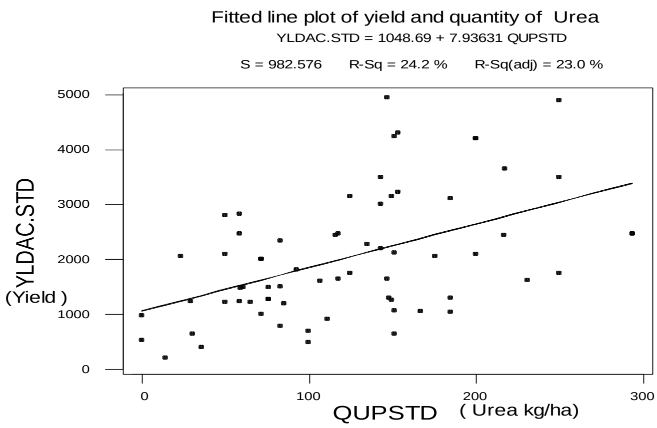

Figure 6. Urea top dressing

The recommended rate and time of urea application according to the maize national research center is maize should be top dressed with urea at the rate of 30 kg N/ha at knee-height growth stage. This is a blanket recommendation and there is no specific recommendation for the study area. Farmers in the study area apply different quantities of urea (0 to 294 kg/ha) and at different crop growth stages. In this study, quantity and growth stage at which urea was applied (urea and urea management) were analysed. 2 out of 68 farmers did not apply urea as top dressing. Urea application significantly increased yield (Adj. R^2 = 23.0 %, P < 0.001). An increase of 1 kg urea/ha increased yield by 7.9 kg/ha.

Urea top dressing at different Crop growth stages
Top dressing of urea at two crop growth stages (vegetative and tasseling) was analysed for their effect on yield. Quantity of urea applied at vegetative crop growth stage significantly increased yield (Adj.R^2 of 41.1%, p <0.001).Quantity of urea applied at tasseling significantly reduced yield (Adj.R^2 of 5.3%, p=0.033).

4.2. Quantified Production Functions

4.2.1. The Production Model

In chapter four, the relationships of land and management and yield were analysed to explore the effect of each land and management parameter versus yields obtained were explored. Some land and management parameters had a significant effect on yield.

YLD(kg/ha) = 1633 - 398 HH + 1423 UP + 3.50 QUP - 21.6 LODG(%)

Multiple linear regression is used to empirically model maize production based on the data collected. Step-wise forward multiple linear regression is applied to select the parameters that are strongly and significantly related to the yield variability. Repeated "trial and error "attempts were carried out to check for correlation between independent parameters and to explore unexpected coefficient values and signs. The final regression equation (production model) was:
:

Table 4. Coefficient and p- value of the production model

Predictor	Coefficient	t-value	P
constant	1633	7.41	0.000
HH	-398	-1.94	0.056
UP	1422	7.07	0.000
QUP	3.49	2.73	0.008
LODG	-21.6	-3.85	0.000

N = 68

R^2(adj.) = 64.9%,

Where,

YLD= Dependent Variable, maize yield (kg/ha)

UP = 1, if the terrain unit is upland plateau

HH= 1, if the terrain unit is highland hill

QUP= Quantity of urea applied as top dressing (kg/ha)

LODG = Lodging (%)

The prepared production model suggests that yields increase if:

- The terrain unit is upland plateau(UP),
- Higher quantity of urea is applied as top dressing.
- There is no lodging.

The regression model explained 65% (Adj.R^2) of yield variability in the study area for one season.

The fitted line between actual and estimated yield shows a high correlation and proved that the production model was useful to predict the actual yield in the area (figure 7).

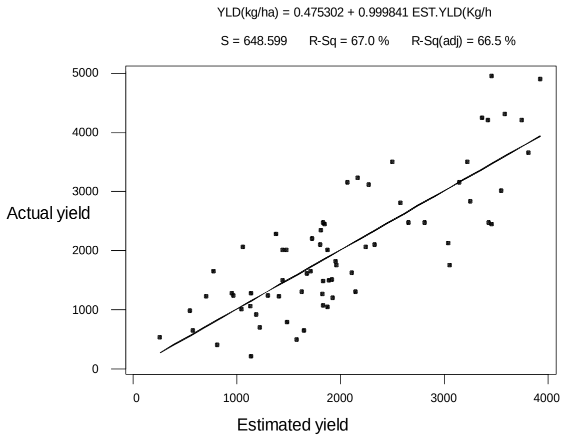

Figure 7 . Actual versus estimated Yield (Adj.R^2=66.5%, p <0.001)

4.2.2. Impact by Yield Constraints

The contribution of each constraint, identified through the model, to the overall yield–gap was calculated by defining two production scenarios: an average and best (optimum) production level scenario. This was established by comparing the average values of the constraint of the 68 plots with the best value of all plots. Difference in yield multiplied by the coefficient of the constraint as suggested by the model indicates for a particular constraint its contribution to the overall yield-gap. The estimated and actual yields represented the “average “and “best “production situations. The relative contribution of yield constraints to the overall biophysical yield-gap for the area is presented in table 5.

Table 5. Impact of yield constraints (kg/ha)

Yield constraint	**Model coeff.**	**Measured value**		**Measured value*Coeff.**		**Partial yield gap**	**% contribution**
		Average	**Best**	**Average**	**Best**		
constant	1633	1	1	1633	1633	0	0
UP	1423	0.24	1	341.52	1423	1081.5	56
HH	-398	0.24	0	-95.52	0	95.52	5
Urea (kg/ha)	3.5	122.5	250	428.75	875	446.25	23
Lod(%)	-21.6	14.1	0	-304.6	0	304.6	16
Total				**2003**	**3931**	**1928**	**100**

Based on data covering one production season only (2000 season), the yield-gap of 1928 kg/ha was caused by the following factors:

- Land factors (terrain units):
  Upland plateau (56%)
  Highland hills (5%)
- Management factor:
- Quantity of urea (23%)
- Lodging (16%)

Lodging occurred as a result of weather (heavy rains) and pests and diseases (stalk borer and stalk rot) effects.

4.2.3. Specific Constraint-Management Relationship

The major yield constraints and their impact on yield were identified through CPA. This approach did not consider specific relationships between identified constraints and management options practised in the area. Analysing specific constraint-management relationships can result in understanding of the land use systems studied and hence improve the yield–gap model. An attempt was made to find a relationship between lodging (a constraint with negative effect on yield) and management aspects that may reduce the impact of lodging.

Variety

The local variety (tall variety) seemed more susceptible to lodging while Rampur yellow, a relatively shorter variety had relatively lower lodging. None of the varieties grown in the area had however a significant effect in reducing the observed lodging.

Urea

Urea applied as top dressing had no a significant effect in reducing lodging (Adj. R^2=0.0%, P =0.682).

Planting method

There was a high score of lodging in fields where broadcasting planting was practised. This effect was again not significant.

None of the management options practised in the area had a significant effect on lodging and lodging as a yield constraint could not be removed from the previous model.

Future breeding programs should focus on developing short and stout varieties with stalk borer and stalk rot resistance to minimize the negative effect of lodging so that the yield gap can be narrowed down.

Improving the Production Model

In the earlier model (section 5.1), 65% of yield variability was explained and the contribution of each constraint to the overall yield-gap was elaborated. The impact of lodging on yield could not be reduced significantly through actual management practice. Further exploration was made to improve (enhance) the earlier production model by considering interactions of Urea (identified constraint in the earlier model) with land and urea management practices as they occur in the study area. Response to urea depends on land characteristics and its management. The relationship between yield and land and management parameters was reformulated as follows:

Yield = f (Land, lodging, urea, Urea *land, urea * urea management)

Response to urea versus land and management parameters

The interaction of quantity of applied urea with land and management parameters was explored to select significant parameters that can be used as input data in step-wise regression. Land parameters such as terrain, soil characteristics (pH and texture), crop growth stage at which urea was applied, and varietal response to urea application were considered. The following interactive parameters had a significant effect on yield (table 11).

Table 6. Effect of interaction of urea with land & management on yield

Urea (kg/ha)	Land parameters			Urea management parameters			
	UP	pH	Fine texture	Variety 1	Time of application	Vegetative growth stage	Tasseling stage
	P<0.001	P<0.001	P= 0.001	P <0.001	P=0.009	P < 0.001	P= 0.033

4.2.4. Final Production Model

Remodelling of the production function was done by considering all land and management parameters that were used as input data for deriving the production model (land, management, and lodging) and new input data (urea* land, urea*urea management) as presented in table 6. Interaction of urea with upland plateau had highly significant effect on yield (R^2=44.97, p< 0.001) but the model still give a preference to the terrain unit "upland plateau ".

Quantity of applied urea was more preferred by the model to urea/urea management interaction. This may be due to the fact that farmers in highland hills and mid-hills are not following appropriate urea management practices. The regression process selected no new interactive parameter. Finally, parameters that were selected in the earlier model were selected once more.

Upland plateau was found to be the most productive terrain unit because of its inherent nature (flat, less erosion hazard, relatively fertile) and optimum management practices followed by farmers such as high quantity of urea with its optimum management and tractor ploughing.

In highland hills, most of applied fertilizer is lost through run off and there is high erosion hazard and farmers did not apply optimum urea management practices causing lower yields.

This study revealed that if Comparative Performance Analysis is based on specific constraint-management functional relationships, such combinations could be found. Use of such combinations could have enhanced CPA methods and the production function. The findings of this CPA study were in line with the farmers` perception of faced constraints for yield differences between actual yields obtained and yields expected.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The following conclusions are drawn from this study.

- Based on one season survey, the production model developed through Multiple Linear Regression successfully explained 65 % of the yield variability in the study area. The production model identified a terrain unit (Upland plateau & Highland hills versus all others), a management parameter (Quantity of applied urea) and lodging as the three major yield constraints. The impact of each identified constraint on yield (yield-gap of 1928 kg/ha) was 61%, 23 % and 16 %, respectively.
- The terrain unit "upland plateau" was found to be potentially the best area to grow maize.
- Basing CPA study on specific constraint-management functional relationship can identify management options that can reduce yield loss induced by a particular constraint. This method could have a wide range of application in Ethiopian production context of diverse agroecosystems and NRM constraints.

5.2. Recommendations

The following recommendations are formulated:

1. Planners, researchers and extension workers may use such research outcomes for priority setting of development interventions.
2. Urea application considerably increases yields, but the exact recommended rate should be examined through soil analysis based on-farm trials on the different terrain units.
3. In the highland hills, appropriate soil and water management practices should be recommended to minimize losses of applied fertilizer through run off.
4. Future CPA studies should consider constraint-management functional relationships and land and management interactions to prepare better yield production functions.

6. REFERENCES

1. Brown, S. 1999. Modelling soil nutrient budgets. Journal of soil use and management, Nepal.
2. De Bie, K. 2000. Comparative Performance Analysis of Agro-Ecosystems. PhD thesis. ITC, The Netherlands.
3. FAO, 1990. Guidelines for soil description. Third edition (revised), Rome.
4. Fresco, L.O. 1984. Issues in Farming Systems Research. Netherlands Journal of Agricultural Science, 32. pp. 253-261.
5. Hind, M. 1999. Comparison of factors affecting maize yield in relation to land tenure system in Zimbabwe. MSc thesis. ITC, The Netherlands.

6. Kadayat, K.B. 1997. Maize research working paper. Lumle Agricultural Research Center, Nepal.

7. Laguna, S.B. 1997. Yield-Gap Analysis for systems with maize, potato and wheat in Bolivia. MSc thesis. ITC, The Netherlands.

8. Lafitte, H.R. 1994. Identifying Production Problems in Tropical Maize: A Field Guide. Mexico, D.F.: CIMMYT.

9. Manipon, E.F. 1996. Impact of the environment and management on paddy yield in Thailand. MSc thesis. ITC, The Netherlands.

10. Moore, S.D. and McCabe, G.P. 1998. Introduction to the practice of statistics. Third edition, W. H. Freeman and Co., New York.

11. Muleya, Z. 1997. Impacts of production methods and environmental aspects on yield of maize cropping systems in Zimbabwe. MSc thesis. ITC, The Netherlands.

12. Ngo, T, A. 2000. Assessing spatial constraints leading to maize yield gaps in Zimbabwe. MSc thesis. ITC, The Netherlands.

13. Olson, K.R. 1986. Use of Multiple Regression Analysis to Estimate Average Corn Yields Using Selected Soils and Climatic Data. Agricultural Systems Journal, 20: 105-120.

14. Pilbeam, C.J. 1999. Poverty, rural livelihood, and land husbandry in hills environment. In: Proceedings of a conference, Silsoe, UK.

15. Poudel, D.D. 1995. Diagnostic survey results in Central Nepal. Journal of farming Systems and Research Extension, Nepal.

16. Regmi, N. 1993. Review of institutions dealing with development policies, planning, and programs in the mountain areas of Nepal. ICIMOD, Nepal.

17. Rossiter, D.G. 1996. A Theoretical Framework for Land Evaluation. Geoderma, 72, 194-197.

18. Wakabi, S.M. 1994. Quantified Land Evaluation for Maize Yield-Gap Analysis. PhD thesis. ITC, The Netherlands.

19. Wakabi, S.M. and Zink, J.A. 1994. Influence of fertilizer application, weeding and insect control on yield and yield-gaps of maize. In: Proceedings of the 15th world congress of soil sciences, Mexico.

20. Zink, J.A. and Farshad, A. 1995. Issues of Sustainability and Sustainable Land Management (SLM). Canadian Journal of Soil Sciences, 75, Canada.