

Chapter IV

Materials and Methods

4.1 Research procedure

Geo-referenced composite soil samples were collected from 103 sites of agricultural land of Guma *geog* in Bhutan for spatial assessment soil fertility. The soil samples were analyzed at the National Soil Services Centre, Semtokha using standard laboratory methods. The soil sample collection sites are presented in Figure 18. The digital land use map produced by the Ministry of Agriculture, Royal Government of Bhutan for 9th Five Year Plan (9FYP) is used as the *geog* land use map (PPD, 2002) and to show different spatial distribution of soil fertility attributes. Generalized research procedure for the study is presented in Figure 17 and description of data collection, field and laboratory works follows.

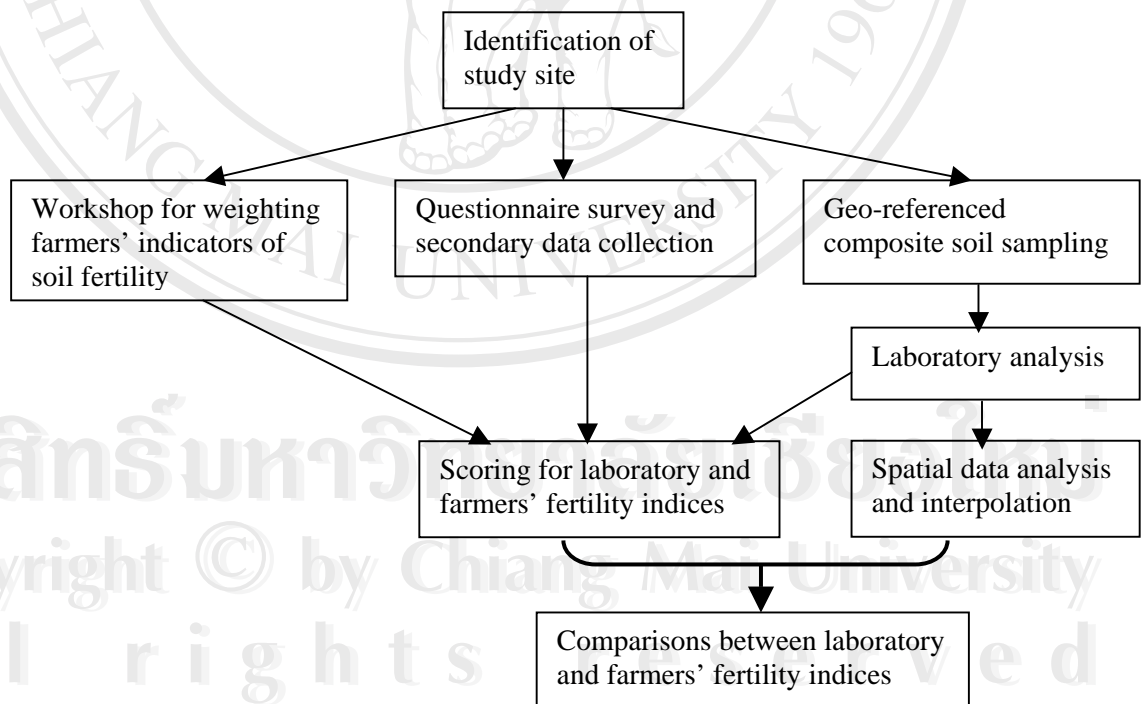


Figure 17: Research procedure.

4.2 Identification of study site

Justifications warranting soil fertility study in Punakha-Wangdue valley are as presented in Chapter 1. This valley consists of two districts of Punakha and Wangdue Phrodang. The RNR-research center, Bajo is located in Wangdue Phrodang which carries out various research in that district although Punakha is also covered by the center, which makes Punakha a choice to conduct research.

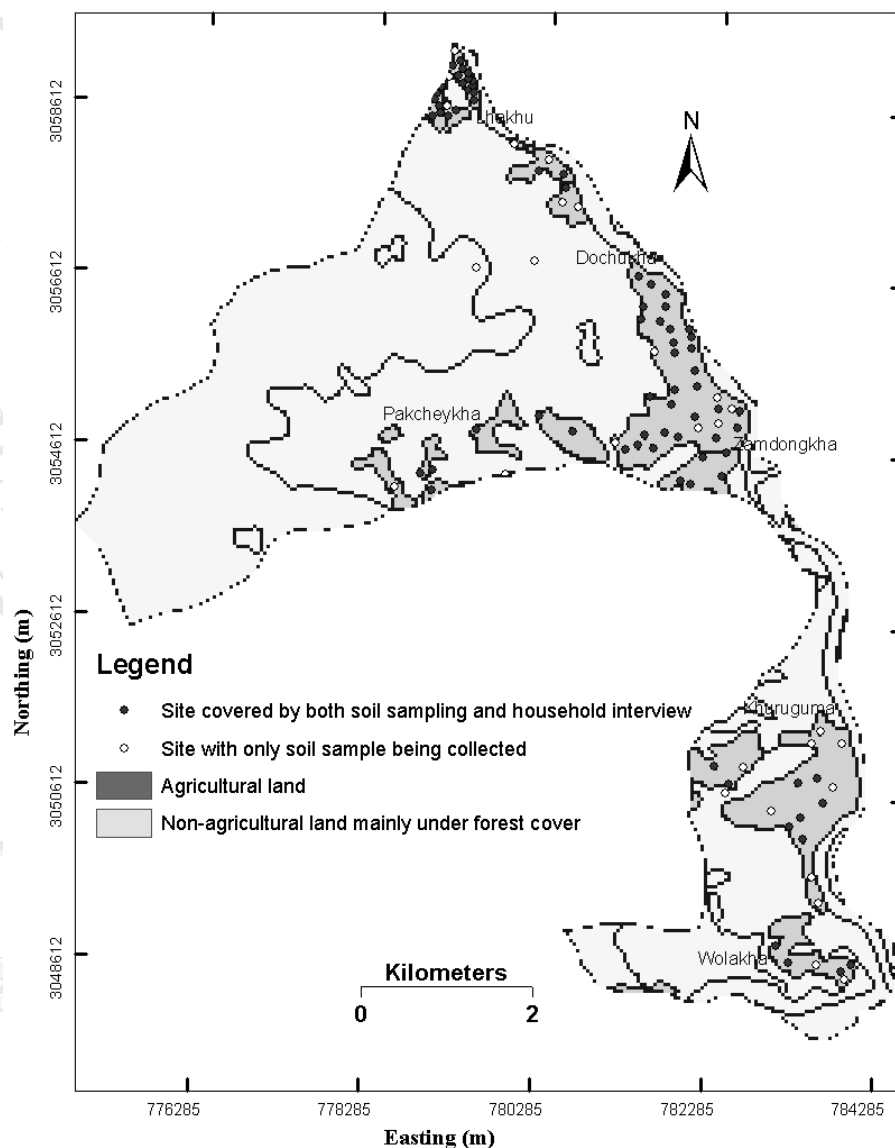


Figure 18. Soil sample collection sites.

Agriculturally, Punakha district is one most important districts in Bhutan. For examples, Punakha has the third largest wet land area and is the second largest paddy rice producing district only after Samtse (MoA, 2002).

There are nine *geogs* of Chubu, Taewang, Lingmukha, Talo, Guma, Dzoma, Kabjisa, Goenshari and Shengana within Punakha district where the author has worked at district level for about five years. Guma *geog* is selected because its land resources are more intensively cultivated as 84.7% of households have access to motorable road by less than an hour's walk (MoA, 2002) and have easy access to their produces as the only market in the district is located within the *geog*. As a result there is a gradual shift from semi-subsistence production to a market driven production system as urban population is rising. Intensification is done mainly with vegetables or wheat/mustard after harvesting rice. In 2000 Guma *geog* alone produced 75.44%, 60.14% and 20.50% of the district's total brinjal, tomato and chili production, respectively, although it is only 6th largest in terms of agricultural land area (MoA, 2002).

Since the cultivation of land is gradually becoming more intensive, knowing the soil fertility status and the state of soil degradation are major concerns. Knowledge of the soil fertility status can be used to generate meaningful relationship to drive a technological package to sustain or increase crop production and can serve as a baseline to commence a nutrient-balance study. A quantitative knowledge on the depletion of plant nutrients may be helpful in devising nutrient management strategies.

4.3 Soil sampling

4.3.1 Soil sampling technique

A *geog* map produced by the Ministry of Agriculture for the 9th Five Year Plan (July 2001-June 2007) was used as the base map for conducting the field survey works (Figure 18). Prior to the actual fieldwork, tentative sampling sites were fixed on the base map. The sampling sites were set in such a way that all the agriculturally

important land use units were proportionately represented. Physical variations like landform, slope, and altitude were also considered before collecting samples. Representative soil samples were collected employing a purposive sampling technique. Soil samples were collected using a soil augur from five to eight points per a site and mixed together thoroughly to make a composite sample. All the composite samples were collected for topsoil (0 – 20 cm) irrespective of land use practice. Sampling was done from last week of March to mid-April in 2004.

Of the total 103 samples collected; 78 were from wet land, eight from dry land, 11 from orchards representing 70%, 16% and 8% the total *geog* agricultural land respectively; and two samples each were from three major forest types of mixed, conifer and broadleaf forests. Other two land uses of *tseri/ pangshing* and kitchen garden accounting 3% each of total *geog* agricultural land were not separately represented because there are no clear delineations between *tseri/ pangshing* and dry land, and orchard and kitchen garden in the farmers' fields as they are located side by side and so they would be represented samples collected in the adjacent fields because they lie in close proximity.

To measure bulk density a separate soil sample for each site was collected using a small metal pipe. The metal pipe was pressed in the ground until the pipe is filled with soil. The filled pipe is removed from the ground and the soil collected in a separate plastic bag. Each bag was distinctly marked with site identification number and purpose of sampling.

4.3.2 Sites geo-referencing

Soil sample collection sites were geo-referenced using a Global Positioning System (GPS) device and the referenced location is from roughly the center of the points that make up a composite soil sample. A total of 103 samples were collected and all the sites were geo-referenced using a GPS device (Figure 19). Both longitude and latitude measures for each location was also recorded against the site identification number. Distribution of soil sample sites for agricultural land is

presented in Figure 18. All soil samples were collected from agricultural land except for a few samples collected from forest soils for comparison purpose.

4.3.3 Topographic data collection

The altitude, aspect and slope for all the composite sample collection sites were measured using altimeter, compass and clinometer, respectively. The topographic information were recorded against the site identification number. The devices used in collection of topographic data collection and metal pipe used for bulk density sample collection are shown in Figure 19.



Figure 19. Data collection devices; A = GPS device, B = compass, C = metal pipe used for bulk density soil sample collection, D = clinometer and E = altimeter.

4.4 Household survey

Information on farmers' perceptions of soil fertility and the indicators they use to assess the fertility status of their fields was gathered through individual partly semi-structured interviews which took place in the interviewee's house using the modified field tested questionnaire (SSF & PNM Project, 1999). The questionnaire format is presented in Appendix IV. The interview was done along with soil sampling and farmers' assessment of soil fertility is restricted to the field of soil sample collection. Farmers' assessment was based on linguistic scale of overall soil fertility of the

particular field. A total of 75 households were surveyed and all the soil sampling sites could not be covered because of either unavailability of owners during the time of survey or the inability of the some occupants to respond in case of rented fields. Topics covered included cultural and soil fertility management practices, farmers' assessment the fertility status of a field on linguistic scale, farmers indicators of soil fertility and socio-economic factors like literacy, demography, land and cattle holding. Perceived trends in FYM availability, livestock bedding materials availability, chemical fertilizer use and family labor availability were also covered. Special care was taken to ensure that the most experienced member of the household was interviewed wherever possible. Interviews were done only with persons that have 10 or more years of experience in farming. Although many farmers distinguish between topsoil and subsoil, during the interviews the discussion was restricted to topsoil. This was done to make sure that what farmers refer and what is analyzed chemically are the same thing by the two knowledge systems, farmers assessment and scientific measurement.

4.5 Secondary data collection

Secondary data were collected from various agencies under the Ministry of Agriculture (MoA). Crops and livestock production data for year 2004 were collected the district agriculture and livestock offices respectively, under Punakha district. Information on overall agricultural facts and figures were obtained from Information Management Section of Department of Agriculture and Planning and Policy Division (PPD) of MoA. GIS spatial data was collected from GIS unit of the PPD, MoA, and the climate data from Agro-met unit of the Council of RNR Research of Bhutan. Information and literature regarding the previous soil fertility activities in the study area were sourced from the National Soil Services Center in Semtokha.

4.6 Soil laboratory analysis

The soil samples collected were dried at room temperature, grinded and sieved. The soil samples were analysed at the Soil and Plant Analytical Laboratory (SPAL) of the National Soil Services Centre (NSSC), Semtokha, Bhutan, for pH

(H₂O), organic carbon (Walkley Black), total N (micro-Kjeldhal), available P (Bray), available K (calcium chloride extraction). Soil texture was analyzed by hand and bulk density measured by dividing oven-dried weight by volume of soil sample. The results of chemical analysis are rated into five classes: very low, low, moderate, high and very high and interpretation of laboratory results is made based on class boundary values presented in Table 15. The designated class boundaries are derived from international sources and standards and are used by the SPAL to interpret chemical analysis reported (AHT, 1995).

Table 15. Guide to interpretation of laboratory results.

	V. Low	Low	Moderate	High	V. High
pH	< 4.5 (ext. acid)	4.6 - 5.5 (v. acid)	5.6 - 6.5 (s. acid)	6.6 - 7.5 (neutral)	> 7.6 (alkaline)
Available K (ppm)	< 40	40 - 99	100 - 199	200 - 299	> 300
Available P (ppm)	< 5	5 - 14	15 - 29	> 30	
Org. C %	< 0.6	0.6 - 1.1	1.2 - 3	3.1 - 4.9	> 5
Total N %	< 0.1	0.1 - 0.19	0.2 - 0.49	0.5 - 0.99	> 1
C:N	< 10	10 - 14	15 - 19	20 - 49	> 50

(Source: AHT, 1995).

4.7 Preparation, exploration, processing and interpolation of spatial data

4.7.1 Creating shapefile and data input in attribute table for use in GIS environment

The geo-referenced sample collection sites were downloaded from GPS to computer and converted to a shapefile for use in the GIS environment. The results of laboratory analysis of organic C, total N, available P, available K, pH, texture, and bulk density for all the sites are entered in attribute table of the above shapefile. Farmers' rating of soil fertility was also entered into the above mentioned attribute table. Interpretation of laboratory results is made based on class boundary values presented in Table 15. The dataset of soil samples is then ready for use in

Geostatistical Analyst for creating prediction surfaces or spatial distribution of soil fertility status.

4.7.2 Spatial data exploration and analysis

Exploratory Spatial Data Analysis (ESDA) tool, an extension of Geostatistical Analyst of ArcGIS version 9 is used to examine the spatial data in different ways. Before creating a surface, data is explored using ESDA to gain a deeper understanding of the phenomena under investigation so as to make better decisions on issues relating to the data. ESDA is used to explore the distribution of the data, search for global and local outliers, search for global trends and to examine spatial autocorrelation (ESRI, 2003). The spatial distribution for available P and K are not normal and others are normal or close to normal and so available P and K data are log transformed before creating a prediction surface. There is weak or no trend except for available P data in which case the trend is removed before interpolation but detrend in the generated prediction surface.

4.7.3 Data processing and interpolation

Geostatistical Wizard, a module in Geostatistical Analyst of ArcGIS version 9 is used to create prediction surfaces. Log transformation is done for available P and K attributes to normalize and other attributes are normal or close to normal. Trend is observed only for available P, the trend is removed while creating a surface but detrend in the output. There was no or only weak trend observed in other attributes. We can choose semivariogram/covariance models to get the best prediction surface by changing model parameters of lag size, lag numbers and anisotropy. A general rule in selecting an appropriate size of lag is that the lag size times lag number should be less than half of longest distance in the study area. It is followed by neighborhood search dialog box where we can specify the number of neighbors to be included in prediction. This will be followed by cross-validation Window that provides with plot of measured against predicted amongst other. We can look at the plot and compare the predicted trend line with 1:1 line and make informed decision. The window provides with different decision prediction errors to help make decision. Generally, the best

model is the one that has the standardized mean nearest to zero, the smallest root-mean-square prediction error, the average standard error nearest to the root-mean-square prediction error, and the standardized root-mean-square prediction error nearest to one (ESRI, 2003).

The interpolation is done using Ordinary kriging method. The kriging interpolation, which is a stochastic, is used because not only does it produce prediction surface but also provides some measure of accuracy unlike deterministic method that provides only prediction surface. The generalized schema of procedural framework is presented in Figure 20. Ordinary kriging can use either semivariance / covariances (mathematical expression of autocorrelation), it can use transformations and remove trends and it can allow for measurement error (ESRI, 2003).

Many prediction surfaces are created using different models and model parameters or both. Best model selected based on statistics of geostatistical layer. Once the appropriate prediction surface is produced, extent of the surface was customized to extrapolate prediction to areas that was not covered by the surface. The customized surface is then clipped to the Guma land use polygon using the Data Frame properties. This is followed by reclassification of spatial distribution to practical levels to enable its usage by farmers as presented in Table 15. The schematic diagram showing the steps in creating thematic soil fertility maps is presented in Figure 20.

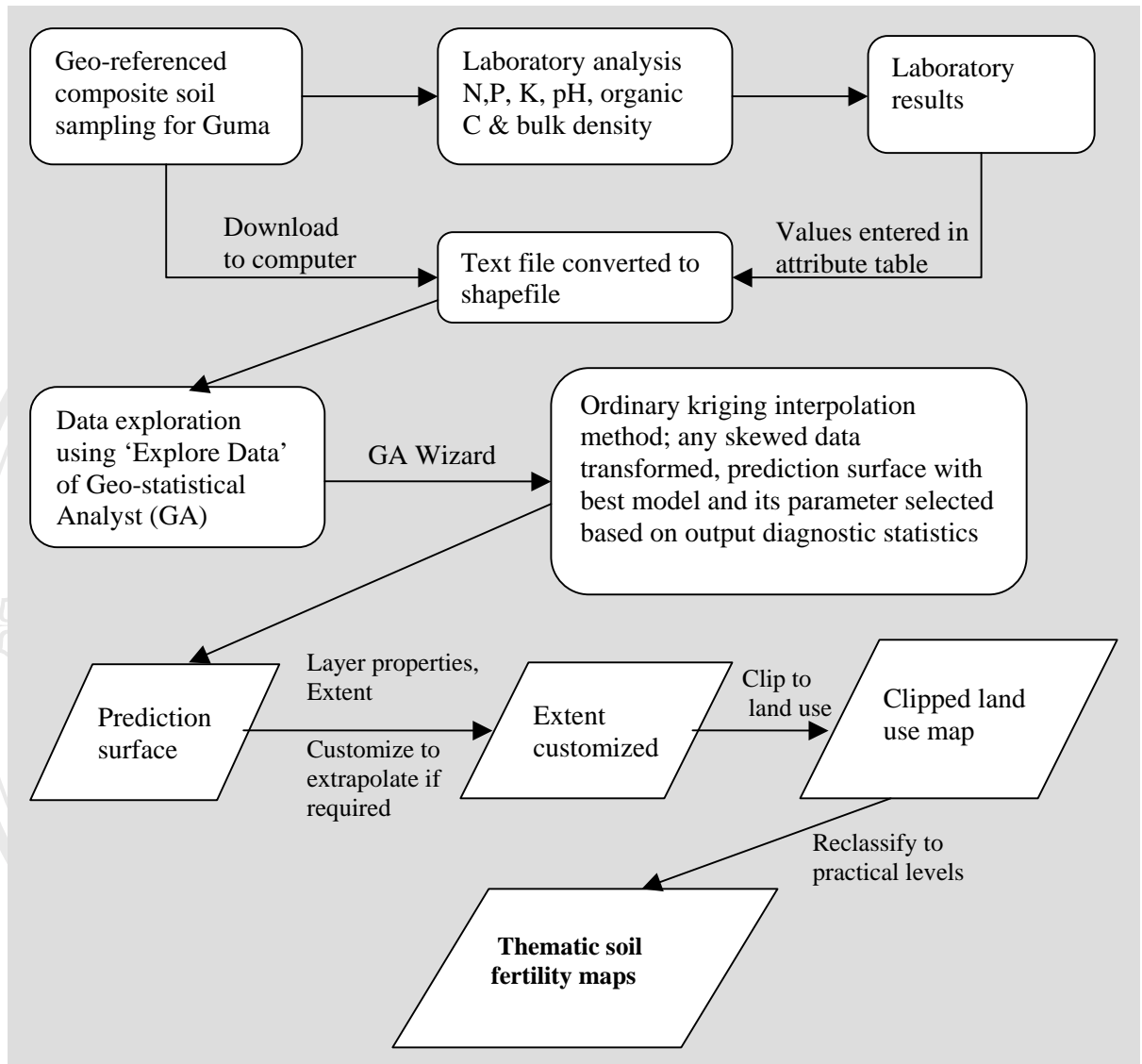


Figure 20. Schema of procedural framework for thematic soil fertility maps.

4.8 Cross-validation and validation

Cross-validation and validation are tools that help us make informed decision as to which model provides the best prediction. Geostatistical Wizard is used to create prediction surface from the known data points and prior to creating the final surface, one should have some idea of how well the model predicts the values at unknown locations. The calculated prediction errors of the created surface serve as useful diagnostic statistics indicating whether the model and/or its associated parameters are reasonable. What cross-validation and validation do is withhold one or more data samples and then make a prediction to the same data location. In this way, we can

compare the predicted value to the observed value and from this get useful information about the kriging model. Cross-validation omits a point and calculates the value at this location using the remaining points. The predicted and actual values at the location of the omitted point compared. This procedure is repeated for second point, third point and so on until all points are covered. For all points cross validation compares the measured and predicted values (ESRI, 2003).

Validation involves dividing data into the test sub-set and the training sub-set and making prediction surfaces for both of the two sub-datasets, and their diagnostic statistics compared. The Create Subset module of the GA is used to created subset data. Other than using data sub-sets in the case of validation the types of graphs and summary statistics used to compare predictions to true values are similar for both validation and cross-validation (ESRI, 2003).

Since validation creates a model for only a subset of the data, so it does not directly check the final model of all available data. But validation only checks, whether a 'protocol' of decisions like choice of semivariogram model, choice of lag size, choice of search neighbourhood is valid. If the protocol works for validation, it also works for whole dataset. GA gives several graphs and summaries of the measurement values verses the predicted values. A scatter plot of predicted verses measurement values show that these should scatter around the 1:1 line for a reasonable model. In general, the best model for a prediction surface is the one that has the standardized mean nearest to zero, the smallest root-mean-square (RMS) prediction error, the average standard error nearest to the RMS prediction error, and the standardized RMS prediction error nearest to one (ESRI, 2003). Table 16 shows the diagnostic prediction statistics of Geostatistical Wizard with interpretations for making judgments regarding the prediction surface being generated.

Table 16. Diagnostic prediction errors and interpretation.

Diagnostic prediction errors	Measure of	Interpretation
Mean	Unbiasedness (centered on measurement values)	Close to zero for a valid model, but depend on the scale of data, so mean standardized need to be consulted
RMS	Closeness of predicted to measures values	The smaller the better
Average standard error	Uncertainty; assessment of quality of variability estimated	Close to RMS for valid model; if it is > RMS then model overestimated the variability and vice-versa
Mean standardized	Unbiasedness (centered on measurement values)	Close to zero for a valid model
RMS standardized	Assessment of quality of variability estimated	Close to one for a valid model, if it is > 1 then model underestimated the variability and vice-versa

(Source: Adopted from ESRI, 2003).

Quality of variability predicted can be judged by comparing the average standard error and RMS prediction error. If the average standard error is greater than the RMS prediction error, then the model has overestimated the variability of predictions and vice-versa. We can also test this dividing each prediction error by its estimated prediction standard error. They should be similar, on average, and so the RMS standardized errors should be close to one if the prediction standard errors are valid. If the RMS standardized errors are greater than one, the variability is underestimated and vice-versa (ESRI, 2003).

4.9 Scoring and comparing laboratory and farmers fertility status

4.9.1 Deriving fertility indices by scoring for laboratory results and farmers' ratings

Farmers' assessment of overall soil fertility based on linguistic scale of poorly fertile, moderately fertile and highly fertile was collected using questionnaire survey. The farmers' fertility scores were derived by converting their linguistic terms of overall soil fertility to numeric values by assigning scores to each of term. Scores were assigned to the farmers' fertility rating of their fields using the inverse ranking technique as Stillwell *et al.* (1981) as: poorly fertile = 1, moderately fertile = 2 and highly fertile = 3.

These scores are treated as the farmers' fertility scores and are hereafter referred to as farmers soil fertility indices. These indices are compared with indices of obtained from chemical analysis of samples in laboratory.

To calculate soil fertility index by laboratory method, the values OM, CEC, BS, available P and available K are used (LDD, 1999). In this study only three attributes of OM, available P and available K are used since other two attributes are not available. In other words, laboratory fertility statuses were calculated from soil organic matter, available P and K by using the same inverse ranking technique as in the case of farmers' scores (Table 17). A conversion factor of 1.724 has been used to convert organic C to organic matter based on the assumption that organic matter contains 58% organic C (i.e., g organic matter/1.724 = g organic C) (Nelson and Sommers, 1996).

Table 17: Conversion of soil fertility attributes to scores.

Category	OM (%)	Available P (ppm)	Available K (ppm)
Low	<1.5	<10	<60
	(1)	(1)	(1)
Moderate	1.5 – 3.5	10 – 20	60 – 90
	(2)	(2)	(2)
High	>3.5	>20	>90
	(3)	(3)	(3)

(Source: LDD, 1999).

The scores of each category is added up to get the overall score or the index value for that category and the summed scores are normalized and reclassified as follows to obtain the laboratory indices. That means that the summed scores are standardized to make them commensurate with farmers' fertility indices. The calculations are done in vector format in the GIS environment.

- a) $1+1+1 = 3$, then the summed scores 1 – 3 is assigned with index 1,
- b) $2+2+2 = 6$, then the summed scores 4 – 6 is assigned with index 2 and
- c) $3+3+3 = 9$, then the summed scores 7 – 9 is assigned with index 3.

Since the farmers' indices are commensurate with the laboratory indices and therefore, point to point statistical comparison can be made. But, point to point comparison is only made for 75 samples all of which are covered by both laboratory analysis and questionnaire survey referring farmers' assessment of overall soil fertility. Other comparison can be made by spatially overlaying the farmers' indices points on the surface created by using all the 97 laboratory indices and see if the surface and points match spatially. For spatial comparison purpose all the 97 laboratory indices are used to produce the best reflection of the reality in the field on which farmers' assessment is based.

4.9.2 Comparison between farmers' and laboratory indices

Comparison between farmers' and laboratory fertility indices were done by two methods. The first method used was spatial one in which farmers' points were overlaid in the surface generated using the laboratory indices for visual assessment. The second method applied was a statistical one: chi-square (χ^2) test of significance, that is, point to point comparison using the statistical package of the SPSS version 12. Since both farmers' and laboratory fertility indices reflect the capacity of the soil to support crop production, these two indices are compared to find their correspondence.

4.10 Assessing weights farmers' indicators of soil fertility

4.10.1 Workshop to weight farmers' indicators of soil fertility

Further to identification of farmers' indicators of soil fertility by individual household survey, a half-day workshop was conducted in April 2005 to further deliberate on their indicators and find weights for each of the indicators of soil fertility. Discussion was held with a total of 11 people: the seven *Geog Yargay Tshogchung* members, three observers of the GYT and the author as facilitator at the GYT hall of Guma *geog* in Punakha (Figure 21). GYT is the decision making body at the *geog* level and it has representation from all the villages and so the decision of GYT is the voice of the people. The GYT members that joined during the discussion were the *Gup* and *Mangmi* (*geog*'s head and deputy head respectively), five *Tshogpas* (village representatives). The observers members of GYT that joined the discussion were the Extension Agents of agriculture, livestock and forestry.



Figure 21. AHP session with GYT members.

4.10.2 Weighting of farmers' soil fertility indicators by AHP

Pairwise comparison between the indicators was performed employing the Analytical Hierarchy Process (AHP) (Saaty, 1980 and Alphonse, 1997). This method involves pairwise comparisons to create a ratio matrix. It takes as an input the pairwise comparisons and produces the relative weights as outputs. Farmers indicators of soil fertility like color, crop yield, texture, soil depth, response to fertilizer, stoniness, compactness, slope and so on are assessed by discussing with farmers through the use of AHP. This is done to determine the farmers' main indicators and more importantly, to determine how they value each of these important indicators. Knowing the weight placed for each of the main indicators will help extension and decision makers to how to go about managing soils related activities in the *geog*.

4.10.3 Weighing of farmers' soil fertility indicators by ranking

Weighting was also done by the ranking method. Straight ranks (most important = 1, second most important = 2, and so on) were obtained as results of consensus reached by the workshop members. Rank sum and rank reciprocal techniques of Stillwell *et al.* (1981) were followed to get weight for each of the five prioritized indicators as follows:

Rank sum method

$$w_i = \frac{n - r_j + 1}{\sum (n - r_k + 1)}$$

where w_i is the normalized weight for the j^{th} criterion, n is the number criteria, here soil fertility indicators under consideration ($k = 1, 2, \dots, n$), r_j is the rank position of the criterion (indicator). Each criterion is weighted $(n - r_k + 1)$ and then normalized by the sum of all weights, that is $\sum (n - r_k + 1)$

Rank reciprocal method

Rank reciprocal weights are derived from the normalized reciprocals of a criterion's or indicator's rank. The formula used for calculating the weights is as follows:

$$w_i = \frac{1/r_j}{\sum (1/r_k)}$$