Chapter V

Soil Fertility Status

This chapter is devoted to presenting the findings and discussion as regards to soil fertility statuses and its spatial distribution over the Guma *geog*'s agricultural land. The findings will directly relate to first objective of the study, which is the determination of spatial distribution of soil fertility statuses. This chapter will further develop basis on how other two objectives can be achieved. The first two sections in this chapter will present findings and discussion on physical location of the sites followed by presenting the findings on soil physical properties of texture and bulk density. Third section will present chemical analysis results, spatial data analysis and distribution of soil fertility statuses followed by the types and trends of soil fertility management practices.

5.1 Physical description of sites: altitudes, slopes and aspects

In terms of altitude, all the sampling locations are within low altitude range (< 2,000 masl) by broad national categorization. More specifically, about 46% of the soil sampled sites were in ranges of 1,220 to 1,300 masl, 32% in 1,300 to 1,400 masl ranges and the remaining 22% of the sampled locations were in 1400 to 1900 masl range. So most of the agricultural land (78%) is within 1,220 to 1,400 masl, since all agriculturally important land use areas are proportionately represented.

As 70% of the total agricultural land in the *geog* is under paddy cultivation, the slope factor is important since steep lands are difficult for paddy rice cultivation. Favorably, 52% of the sampled locations were in gentle slopes of 2 to 14%. About 29% of the samples were from moderately sloping (14 to 25%) land and the remaining 19% were from steep slopes of > 25%. Most agricultural land is located in the valley of river Puna Tsangchhu and Ngakalumphu stream.

Maximum percentage of sites (34%) are in north-easterly aspects and minimum percentage sites (6%) are facing south. Twenty-five percent sites face east and the other aspects include north, south-east, north-west and south as shown in Figure 22.

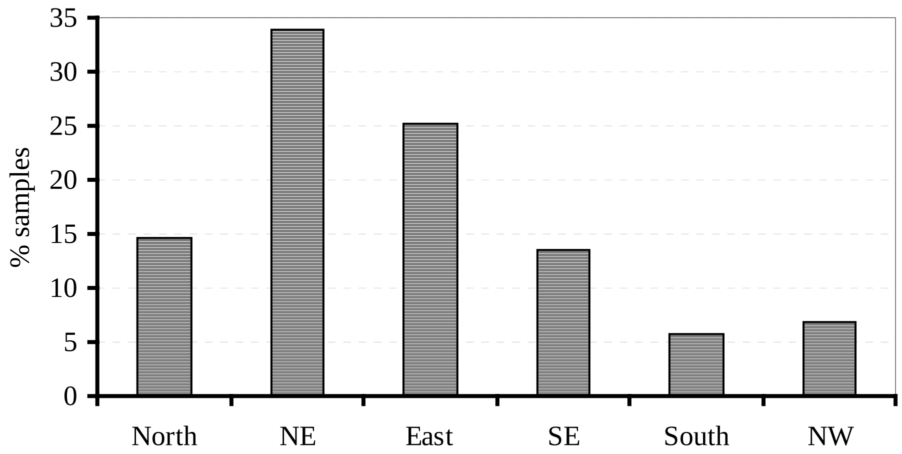

Figure 22. Aspects of sampled locations.
(Source: Survey, 2005).

5.2 Soil physical properties

5.2.1 Bulk density

Bulk density can be used to determine if soil's degree of compactness would allow root penetration and soil porosity. Porosity is the ability of soil to absorb and transmit moisture and air. As bulk density increases the ease of penetration by plant roots and porosity decreases and vice-versa. That means lower bulk density values are better for root penetration due to better porosity with good available water (moisture) holding capacity (AWHC). Bulk densities that limit plant growth vary for soils of different textural classes (Arshad *et al*., 1996; Handreck and Black 1994). Many soils in Bhutan are said to have low bulk densities and that the normal correlation between soil texture and AWHC do not hold (BSS/NSSC, 2003). In the study area, bulk density values in the ranges of 0.97 to 1.59 g/cm^3 with mean value of 1.28 g/cm^3, which means that the values are in ideal or non-limiting ranges for plant root penetration and porosity by Arshad *et al*., 1996 categorization. The land use wise summary statistics for bulk density is presented in Table 19.

5.2.2 Soil texture

About 35% of all soil samples were in sandy clayey loam type (SCL), about 26% in loamy sand (LS), about 18% in sandy loam (SL), about 15% in loam (L) and the remaining 6% of the samples had clayey loam (CL) and sandy clay (SC) textures. These figures are expressed as a percentage of total samples by texture type.

The village wise texture of the soil samples given in Table 18 shows that maximum number of soil samples in Zamdongkha (12), Dochukha (8) and Lakhu (8) have sandy clayey loam texture. Most of samples in loamy sand occur in Lakhu (21) followed by Pakcheykha (3) and one each in other villages except for Wolakha village.

Table 18: Village wise soil texture.

Soil texture	Number of samples in each village					
	Dochukha	Khuruguma	Lakhu	Pakcheykha	Wolakha	Zamdongkha
CL	-	3	-	-	3	-
L	1	5	2	2	-	5
LS	1	1	21	3	-	1
SC	-	-	-	-	-	1
SCL	8	2	8	-	5	12
SL	2	4	8	3	-	2

(Source: Soil texture by hand, April 2005).

5.3 Spatial distribution of soil fertility statuses by laboratory and farmers' methods

5.3.1 Interpretation of laboratory results and descriptive statistics

At a glance assessment and visualization of soil analysis results presented in Figure 23 shows that most of the values of fertility attributes are in the very low, low and moderate categories. The pH of the soil is reasonable with 61% of samples in moderate and high categories (Figure 23). The soils are very poor in total N with 73% of the soil samples in very low category and the rest 27% in low category. Soils are also poor in available P and slightly better in available K and organic C compared to total N and available P.

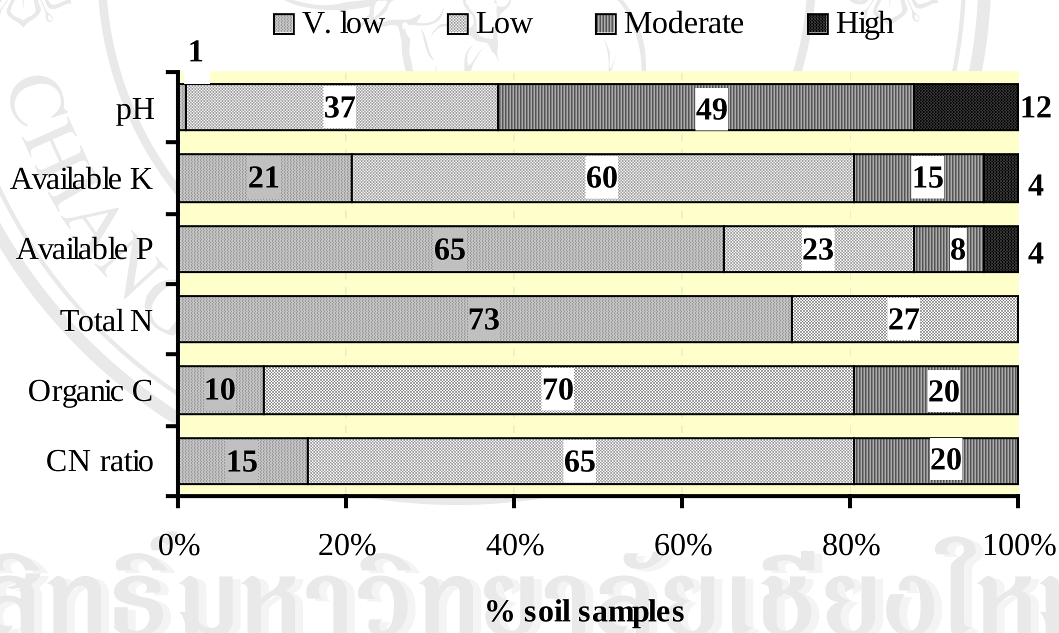

Figure 23. Soil laboratory results.
(Source: Soil laboratory analysis, April 2005).

Mean soil pH value in wet land is 5.53, which is very acidic (low) compared to 6.54 for dry land and 6.66 for orchards that fall into moderate or slightly acidic category (Table 19). The mean pH values from forest samples are moderate, but more acidic than dry land and orchards, but less acidic compared to wet land value. Mean of organic C% is low in wet land, but is moderate in dry land and orchards soils, its value for mixed forests even lower than that of wet land. Mean organic C% for conifer and broadleaf forests are within moderate category. Mean total N% is in very low category in all land uses except in dry land where the value falls into low category. Due to the very low or low total N levels, C:N ratios are favorable (i.e. low or very low). Mean available P (Ava. P) values are in very low category in mixed and conifer forests; in low category in wet land, dry land and broadleaf forest; and moderate in orchards. While mean available K (Ava. K) values are is better than those of available P with dry land and orchards in moderate category and others in low category. The bulk density (BD) mean values ranges from 0.98 g/cm^3 for conifer forest to 1.36 g/cm^3 for broadleaf forest. The detailed land use wise descriptive statistics of the soil fertility attributes and bulk density resulting from soil chemical analysis are presented in Table 19.

Table 19. Descriptive statistics of results of soil laboratory analysis of seven land uses.

Land use	Descriptive statistics	Soil fertility and physical attributes					
		pH	Org. C (%)	Total N (%)	Ava. P (ppm)	Ava. K (ppm)	BD (g/cm^3)
Wet land	Mean	5.53	0.95	0.078	5.15	57.77	1.29
	Std. error	0.040	0.028	0.002	0.703	3.370	0.012
	Std dev	0.352	0.252	0.021	6.209	29.761	0.110
	Range	2.59	1.4	0.09	28.13	186.14	0.53
	Minimum	4.89	0.1	0.04	0.09	19.7	1.06
	Maximum	7.48	1.5	0.13	28.22	205.84	1.59
	n	78	78	78	78	78	78
Dry land	Mean	6.54	1.25	0.101	9.94	161.05	1.32
	Std. error	0.109	0.113	0.007	4.700	25.408	0.050
	Std dev	0.309	0.321	0.020	13.294	71.864	0.142
	Range	0.96	0.8	0.06	39.73	184.82	0.33
	Minimum	6.01	0.8	0.06	2.38	42.26	1.17
	Maximum	6.97	1.6	0.12	42.11	227.08	1.5
	n	8	8	8	8	8	8
Orchard (citrus)	Mean	6.66	1.15	0.079	14.48	130.35	1.27
	Std. error	0.110	0.146	0.011	5.262	15.854	0.039
	Std dev	0.364	0.484	0.036	17.451	52.582	0.129
	Range	1.19	1.5	0.1	46.28	195.43	0.45
	Minimum	6.12	0.4	0.02	0.77	36.71	1.08
	Maximum	7.31	1.9	0.12	47.05	232.14	1.53
	n	11	11	11	11	11	11
Mixed forest	Mean	5.97	0.75	0.040	1.78	48.795	1.07
	Std. error	0.415	0.05	0.01	0.37	12.175	0.155
	Std dev	0.587	0.071	0.014	0.523	17.218	0.219
	Range	0.83	0.1	0.02	0.74	24.35	0.31
	Minimum	5.55	0.7	0.03	1.41	36.62	0.91
	Maximum	6.38	0.8	0.05	2.15	60.97	1.22
	n	2	2	2	2	2	2
Conifer forest	Mean	5.61	1.45	0.09	4.55	81.22	0.98
	Std. error	0.235	0.150	0.020	3.240	45.260	0.010
	Std dev	0.332	0.212	0.028	4.582	64.007	0.014
	Range	0.47	0.3	0.04	6.48	90.52	0.02
	Minimum	5.37	1.3	0.07	1.31	35.96	0.97
	Maximum	5.84	1.6	0.11	7.79	126.48	0.99
	n	2	2	2	2	2	2
Broadleaf forest	Mean	5.78	1.15	0.055	7.98	43.85	1.36
	Std. error	0.235	0.050	0.005	0.400	1.270	0.235
	Std dev	0.332	0.071	0.007	0.566	1.796	0.332
	Range	0.47	0.1	0.01	0.8	2.54	0.47
	Minimum	5.54	1.1	0.05	7.58	42.58	1.12
	Maximum	6.01	1.2	0.06	8.38	45.12	1.59
	n	2	2	2	2	2	2

(Source: Soil laboratory analysis, April 2005).

5.3.2 Data exploration results for kriging interpolation

Exploratory Spatial Data Analysis (ESDA) tool is used to examine the distribution of spatial data in different ways. The kriging interpolation requires data to be normally distributed. Normality of the data was examined by observing histogram and normal plot of data distribution, kurtosis values, closeness of mean and median. Spatial data distribution statistics for normality assessment is shown in Table 20. Mean and median are measures of center of a data distribution, closeness of these two values to each other indicates the distribution to be close to normal (ESRI, 2003). Mean and median values of total N, organic C, pH and bulk density are close to each other suggesting that these data are close to normal, while the values of available P and K are not close and so are not close to normal. The shape of distribution can assessed by skewedness coefficient and symmetric distribution has a skewedness coefficient of zero. Distribution of available P and K and pH are skewed, other distribution are close to symmetry. A normal distribution has kurtosis value of 3.00 and if the kurtosis of a distribution is close to 3.00 then the distribution is close to normal (ESRI, 2003). By looking at the kurtosis values, except for available P and K others are close to normal. Further, normality was assessed using ‘Normal QQplots’ (Appendix II) and trend in the data was analyzed using ‘Trend Analysis’ (Appendix III). 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.

Table 20. Spatial data distribution statistics for normality assessment.

Statistics	Total N (%)	Available P (ppm)	Available K (ppm)	Organic C (%)	pH	Bulk density (g/cm^3)
Mean	0.080	6.638	74.097	1.005	5.734	1.282
Median	0.079	3.120	53.890	1.000	5.560	1.290
Kurtosis	2.582	10.003	4.673	3.486	3.779	2.967
Skewedness	0.062	2.5945	1.617	0.239	1.185	-0.016
'Normal QQplots'	Close to normal	Not normal	Not normal	Close to normal	Close to normal	Close to normal
n = 97						

5.3.3 Cross-validation and validation of prediction surfaces

For validation purpose, the dataset was divided into training subset and test subset and prediction surfaces for different soil fertility attributes created. The training set consists of 68 points (70%) and the test set of 29 points (30%). The prediction surfaces for different soil fertility attributes were created using the two data subsets and their diagnostic statistics compared. Validation is performed by following the same 'protocol', meaning that same model and model parameters are used as is used to produce final prediction surface with whole dataset. If the protocol works for validation test dataset, it also works for whole dataset (ESRI, 2003). Since the diagnostic statistics for training subset and test subset are similar (Table 21), that means that these protocols works for the whole data set.

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. Except 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). The diagnostic prediction error statistics of best model for each of available P and K, total N, Organic C, pH and bulk density is presented in Table 21.

Table 21. Cross-validation and validation for soil attributes.

Attribute	Prediction errors:	**Cross-validation** Training dataset, 68 points (70%)	**Validation** Test dataset, 29 points (30%)
Total N (%)	Mean	-0.01206	0.00918
	Root-mean-square (RMS)	0.3192	0.2782
	Av. standard error	0.3017	0.3021
	Mean standardized	-0.0366	0.03513
	RMS standardized	1.055	0.920
Available P (ppm)	Mean	-0.004927	-0.1788
	RMS	5. 956	6. 227
	Av. standard error	10.36	6.349
	Mean standardized	-0.06631	-0.02859
	RMS standardized	0.7152	0.9781
Available K (ppm)	Mean	-0.04248	-0.06623
	RMS	52.95	41.7
	Av. standard error	49.43	49.36
	Mean standardized	-0.002504	-0.002806
	RMS standardized	1.081	0.844
Organic C (%)	Mean	-0.007041	0.1839
	Root-mean-square	0.02245	40.79
	Av. standard error	0.02201	49.61
	Mean standardized	-0.02458	0.01105
	RMS standardized	1.015	0.828
pH	Mean	-0.008659	-0.1164
	RMS	0.5358	0.5241
	Av. standard error	0.5285	0.5299
	Mean standardized	-0.01365	-0.2143
	RMS standardized	1.008	0.982
Bulk density (g/cm^3)	Mean	0.002568	0.009506
	RMS	0.1159	0.1302
	Av. standard error	0.1104	0.1106
	Mean standardized	0.02252	0.07333
	RMS standardized	1.048	1.166

The prediction error statistics in Table 21 show that for both cross-validation and validation the statistics are similar. In both training and test subsets, the standardized means are near to zero, the root-mean-square prediction errors are small, the average standard errors near to the root-mean-square prediction errors, and the standardized root-mean-square prediction errors are near one. There are small differences between the statistics but both are towards required values and the output produced from using the whole dataset shows even better statistics. Therefore, the output produced is taken to be valid.

5.3.4 Interpolation and determination of spatial distribution of soil fertility statuses by laboratory method

Several prediction surfaces were created using different models and model parameters with the whole set of data and the best model was selected based on best prediction statistics. 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 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). Spatial distributions of total N (%), available P (ppm), available K (ppm), organic C (%), soil pH and bulk density (g/cm^3) are presented in Figures 24, 25, 26, 27, 28 and 29, respectively . The most of the land areas are poor in N, P, K and organic C. Soil pH is relatively better compared to other soil fertility attributes.

5.3.4.1 Total nitrogen (%)

Most of total N distribution fell in ‘very low’ (0.02 - 0.1%) category followed by a small part in low (0.1-0.13%) category. All the agricultural lands under Lakhu, Zamdongkha, Khurguma, Lakhu and most part of Pakcheykha and Wolakha are under very low levels of total N. Only some part Pakcheykha and a small part of Wolakha under slightly better and low level of total N (Figure 24).

5.3.4.2 Available phosphorus (ppm)

The available P distribution shows that the ‘very low’ (0.18 – 5.00 ppm) category occupies most of the land followed by ‘low’ (5.00 – 14.00 ppm) category. Except for some areas in Lakhu in moderate and high level, all lands are under low and very low levels of available P (Figure 25). Most of the wet lands of Khuruguma, Wolakha and Zamdongkha are under very low level of available P.

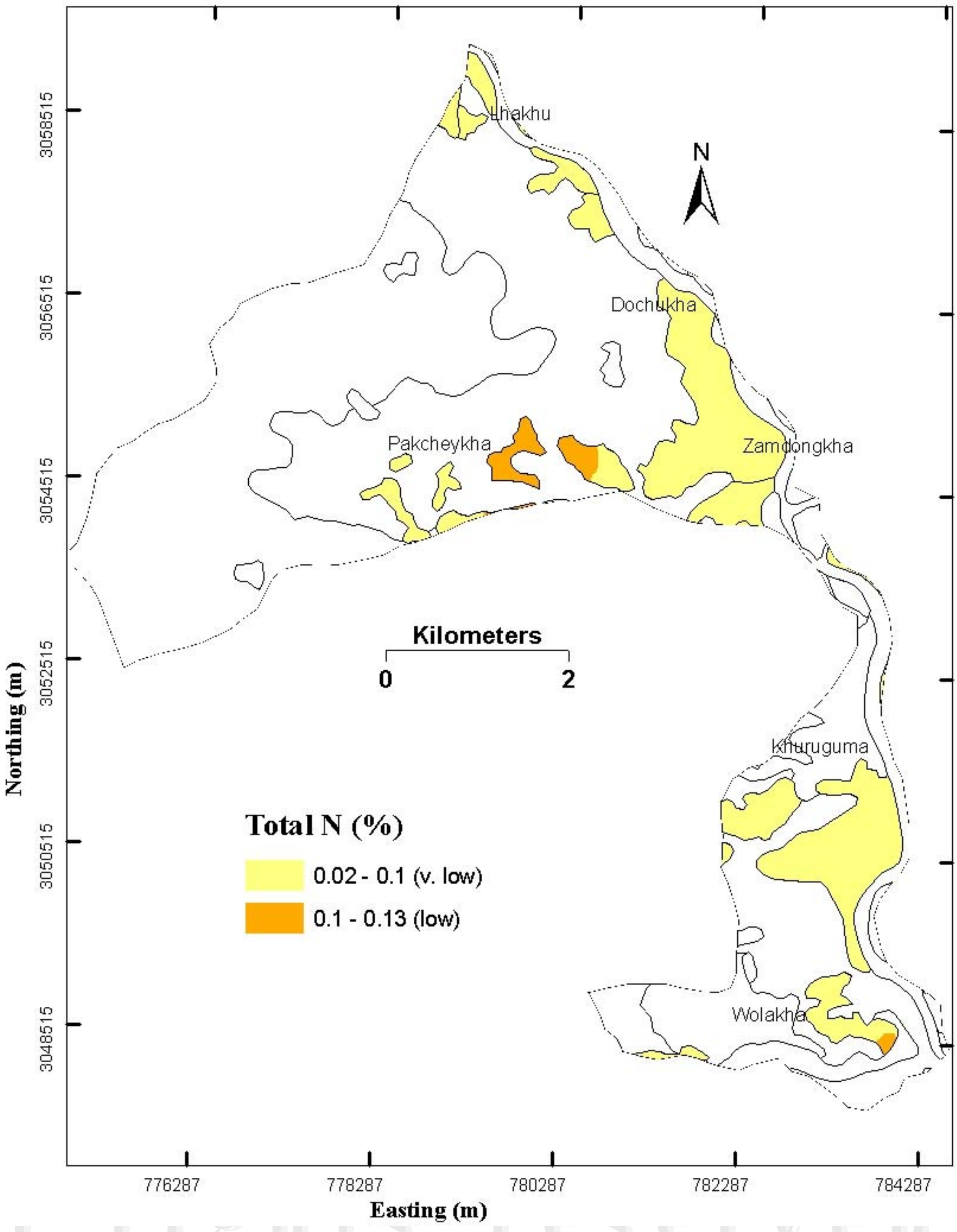

Figure 24. Spatial distribution of total N (%).

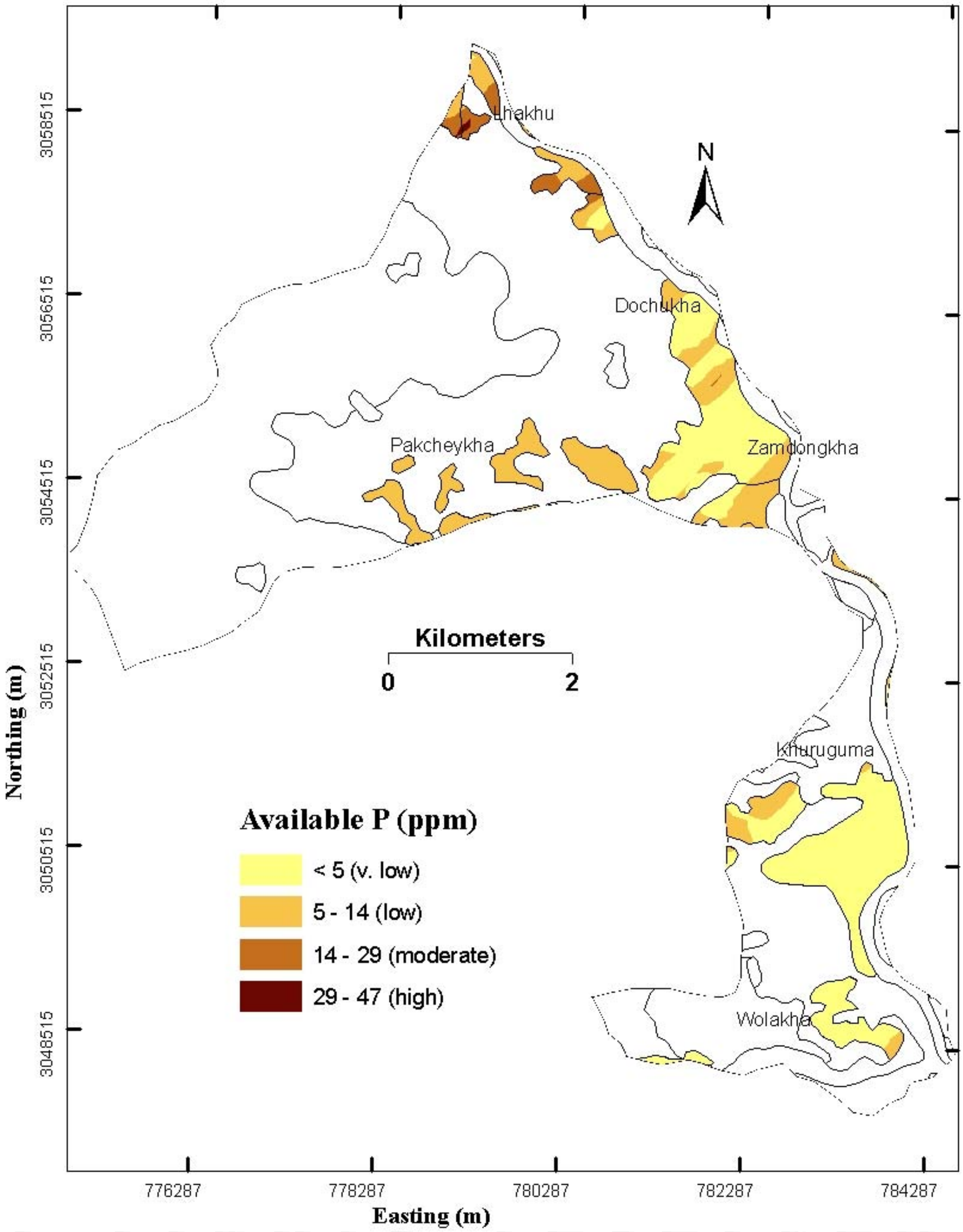

Figure 25. Spatial distribution of available P (ppm).

5.3.4.3 Available potassium (ppm)

For available K, 'low' (40 – 99 ppm) category occupy most of the land followed by 'moderate' (100 –199 ppm), 'very low' (< 40 ppm) and 'high' (200 – 299 ppm) categories. Lands across all the six villages are also in low levels of available K except for some lands in Khuruguma, Zamdongkha and Lakhu (Figure 26) that fall under moderate category. Very low available K is only found in small area in Lakhu village. The fertility status is slightly better for available K compared to available P whose distribution shows most of lands under very low category.

5.3.4.3 Organic carbon (%)

The results for organic C show that most of agricultural land area fell in the 'low' category (0.7 – 1.1%) followed by 'moderate' category (1.1 – 1.9%) and small part fell in the 'very low' category (Figure 27). Spatial distribution of soil organic carbon shows that Pakcheykha and Wolakha villages have moderate level of soil organic C and rest of lands are in low level except for small areas in Khuruguma and Lakha villages with moderate levels.

5.3.4.5 Soil pH

Unlike other attributes soil pH of 'moderate'(5.5 –6.5) category occupies most of the land followed by 'low' (4.6 – 5.5) and 'high'(6.5 – 7.48) categories. Except for some lands in Zamdongkha, Khuruguma and Lakhu all the lands are under moderate soil pH (Figure 28). Twelve percent of samples (Figure 23) were in high soil pH values and these cannot be seen in small map. Soil pH amendments are only needed in those areas with low pH.

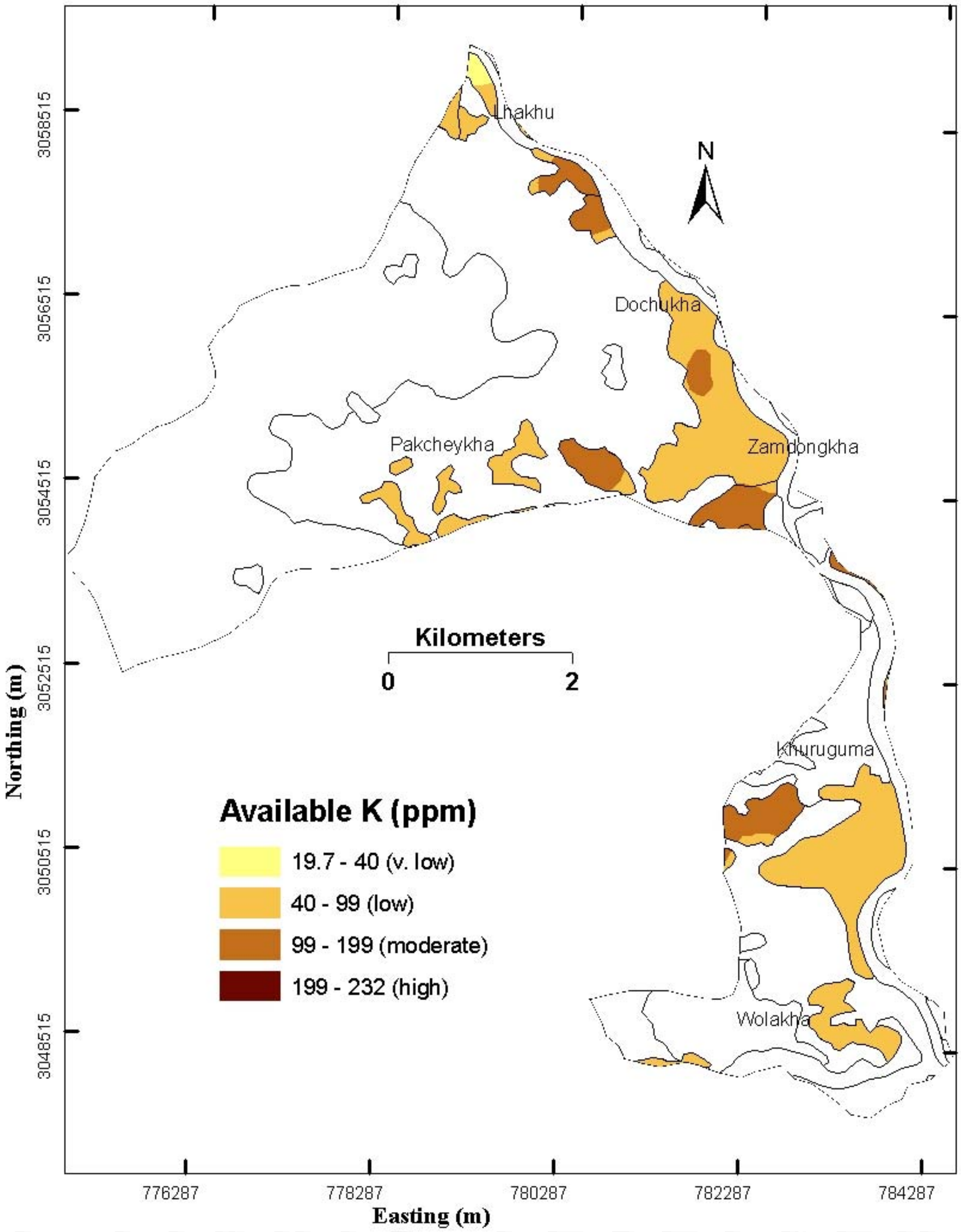

Figure 26. Spatial distribution of available K (ppm).

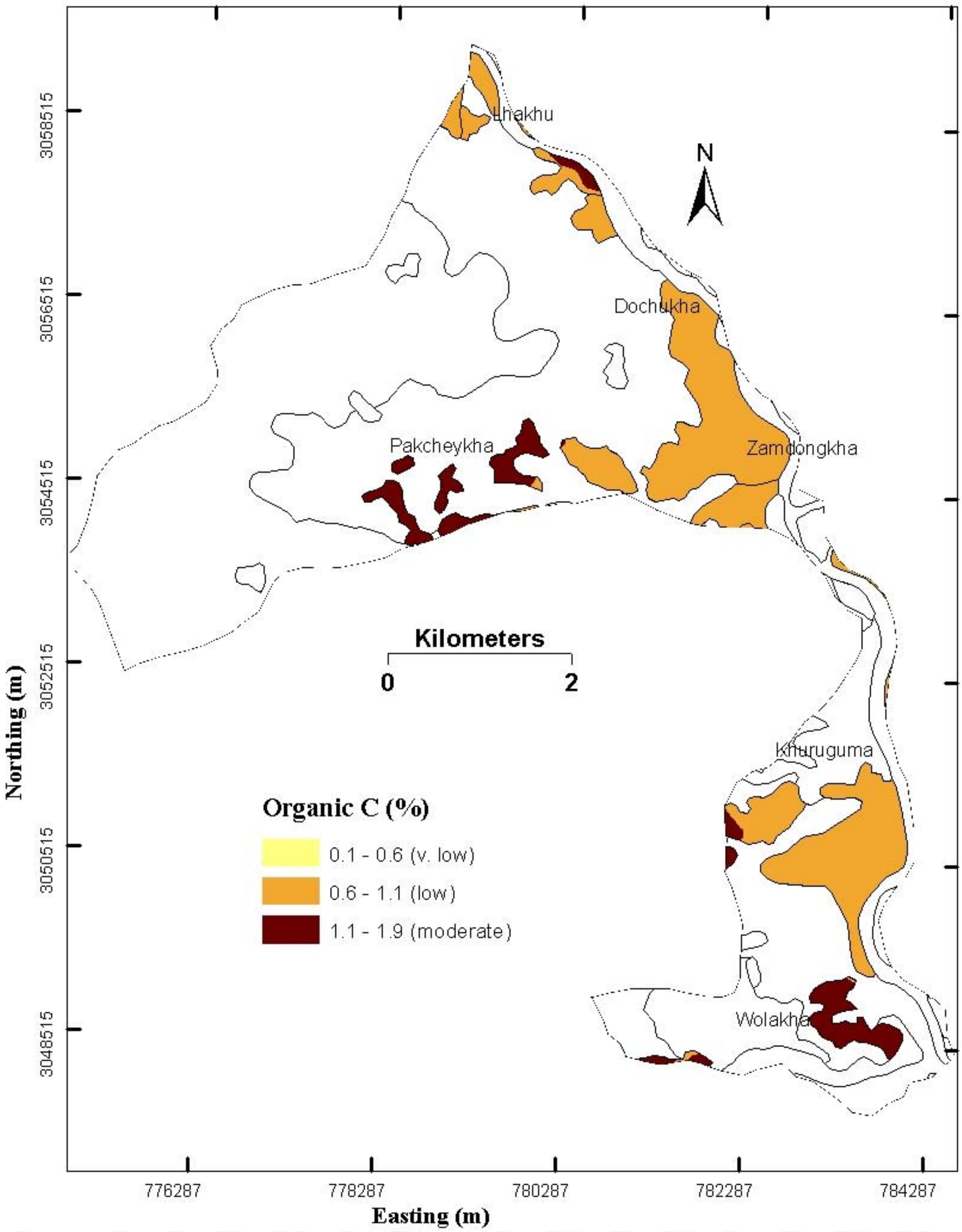

Figure 27. Spatial distribution of soil organic C (%).

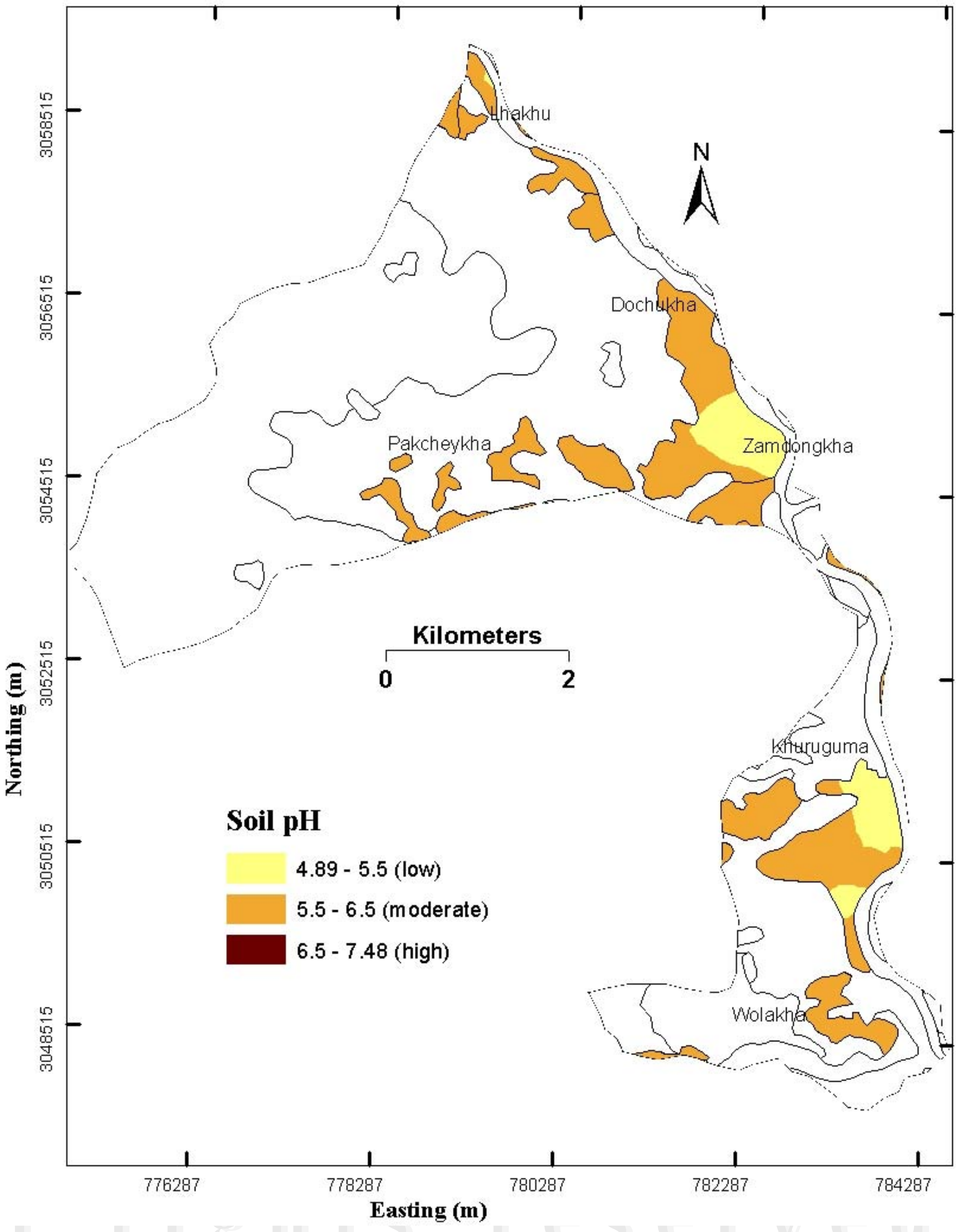

Figure 28. Spatial distribution of soil pH.

5.3.4.6 Bulk density (g/cm^3)

Many soils in Bhutan are said to have low bulk densities (BSS/NSSC, 2003). In the study area, bulk density values are in the ranges of 0.97 to 1.59 g/cm^3 with mean value of 1.28 g/cm^3, which means that the values are in ideal or non-limiting ranges for plant root penetration and porosity by Arshad *et al*., 1996 categorization. Bulk density values in 1.31 to 1.41 g/cm^3 and above are found in southern and center of the *geog* and values in 1.25 to 1.31 g/cm^{3}and less are in northern and center in the study *geog* (Figure 29). Pakcheykha and Lakhu villages are both in 1.25 to 1.31g/cm^3 and 1.15 to 1.25 g/cm^3 bulk density categories. As far as plant root penetration and soil porosity is concerned the bulk density values are in the non-limiting range.

5.3.4.7 Other studies

There is no other soil fertility study that covers the whole *geog*, but there are a few done at orchard to district level depending upon the purpose. For village level (BSSP, 1999b) that covered Zamdongkha and part of Pakcheykha village (Nyakulumpa valley); two orchards level studies (SSU/NSSC, 2003) for Ritcha in Dochukha and (BSS/NSSC, 2005) for Dabchegang near Zamdongkha village. NSSC *et al*. (2002) was done representing citrus orchards of Punakha district.

BSSP (1999b) conducted a study in Zamdongkha and part of Pakcheykha village (Nyakulumpa valley) and the study reported that organic C, total N and available P varied from very low to low while in this study total N (Figure 24) and available P (Figure 25) are in line with their finding, but organic C is in only low level (Figure 27). BSSP (1999b) found available K to be mostly low and in this study too available K levels are mostly low and in part of Pacheykha it is moderate (Figure 26). The fertility statuses can change over time and BSSP (1999b) was conducted in 1999 as compared to this study in 2005.

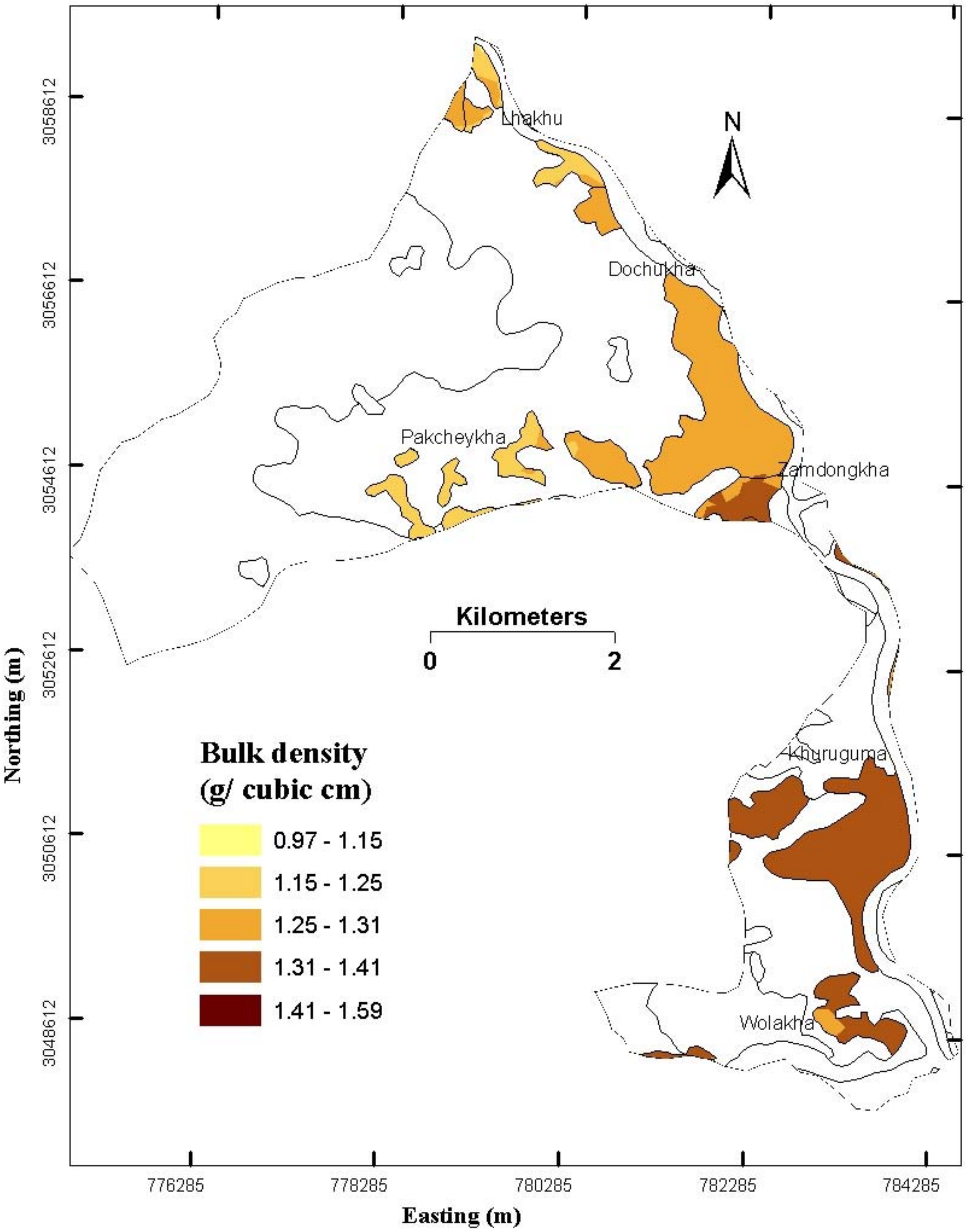

Figure 29. Spatial distribution of soil bulk density (g/cm^3).

5.3.5 Spatial distribution of soil fertility by farmers' perceptions

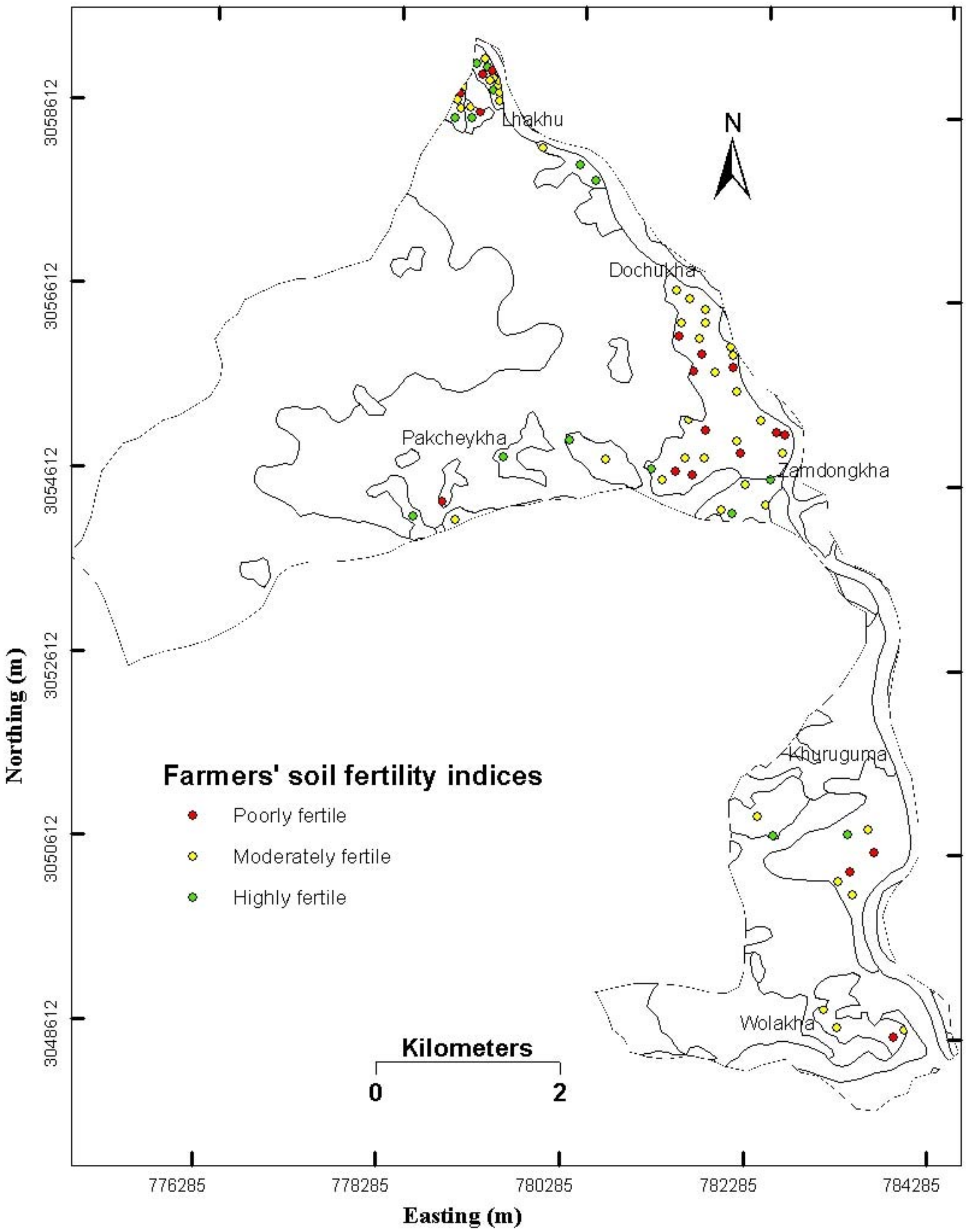

Figure 30. Spatial distribution of soil fertility by farmers' subjective assessment.

Spatial distribution of soil fertility by farmers' subjective assessment in three categories of poorly fertile, moderately fertile and highly fertile is presented in Figure 30. The poorly (red filled circles), moderately (amber filled circles) and highly (green filled circles) fertile classes have 18, 41 and 16 sites, respectively.

5.3.6 Soil fertility management practices

The soil fertility management practices adopted by farmers in the study area are use of FYM and fertilizer, tethering livestock and burning trash in the fields (Figure 31). Practices of using FYM and chemical fertilizers of urea and s*uphala* are being practiced by 92% of the surveyed households. The practices of tethering livestock and burning of trash residues are being practiced by 28% and 16% of surveyed households, respectively.

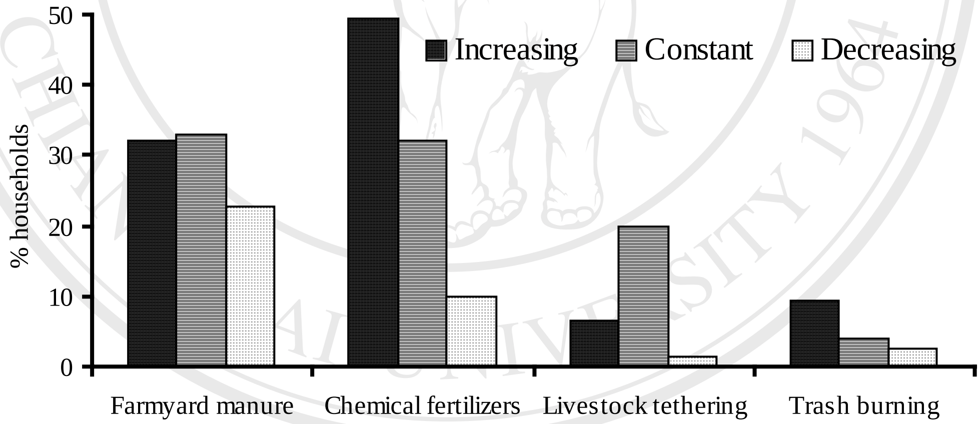

Figure 31. Soil fertility management practices in the study area.
(Source: Survey, 2005).

Figure 31 shows the trends of the four soil fertility management practices over last five to 10 years. The percentage of farmers using FYM is on decline and there is a sharp rise in the case of chemical fertilizers and trash burning practices. Livestock tethering has been practiced by rather constant percentage of farmers over the last five to 10 years. Trash burning has become popular amongst chili growers especially in preventing carrying over of chili blight fungus to the next cropping season.

5.3.6.1 Village wise trends in availability of FYM and its factors

Spatial distribution of soil organic carbon (Figure 27) shows that Pakcheykha and Wolakha villages have moderate level of soil organic C and the rest of lands are in low level except for small areas in Khuruguma and Lakha villages with moderate levels. It might be of interest to dual into the trends of FYM in different villages in the study *geog*. Pakcheykha and Wolakha villages with moderate organic C have been experiencing shortage of FYM and the explanation for the moderate organic C may be that these villages have forests in close proximity contributing some soil organic matter. Low level of organic C in other villages is due to shortage of FYM and the trends in FYM usage by farming households of six villages over last five to 10 years is demonstrated by Figure 32. In all the six villages number households reporting a decreasing trend is the maximum. Why is there such as decline? It definitely warrants further inquiry into the cause of this trend.

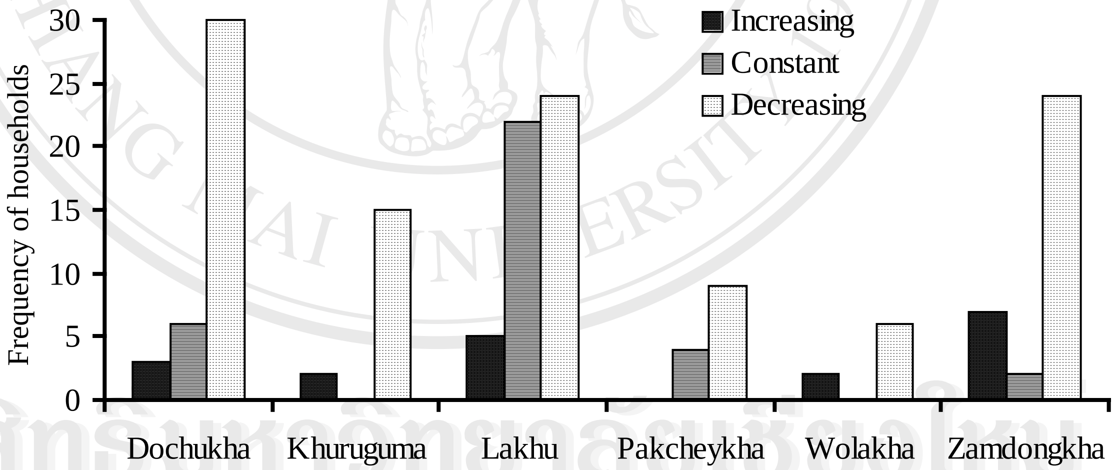

Figure 32. FYM availability trend in last five to 10 years.
(Source: Survey, 2005).

The most important reasons reported by HH for decline in FYM availability are reduction in cattle holding, shortage of farm labor and decreased availability livestock bedding materials. The correlations (*r*) between FYM availability trend and trends of size of cattle holding, availability of livestock bedding material and labor availability are: 0.65, 0.32 and 0.28, respectively. That means that the decreases in cattle holding size, farm labor and bedding materials are attributable to decline in FYM availability. However, the strong and positive correlation (r = 0.65) between FYM availability trend and trend of size of cattle holding suggests that the reduction in the cattle holding size to be most important factor causing reduction in FYM availability. Maximum number of households reported decreasing trend of livestock. This is because of increase in the number of more productive cross-bred cattle at the expense of a more rapid decrease in the number of less productive local breeds at national and local level (MoA, 1999). In general, the decreasing trend is due to replacement of large local herd size by few improved cattle that has led farmers to shift from extensive (grazing) through semi-extensive (tethering) to intensive (stall feeding) systems.

Decreasing in cattle numbers reduces the supply of FYM even though dung recovery is greater in the intensive systems compared to extensive systems (Norbu and Floyd, 2004). In the study area, farmers practice all the three types of cattle farming, extensive, semi-intensive and intensive and these together are not able meet FYM requirement that was possible five to 10 years ago. Reduction in cattle population is to some extent attributable to shortage in farm labor.

5.3.6.2 Village wise trends in chemical fertilizers use

From the spatial distribution of current soil fertility statuses, one can see that soils in general are poor in all the six villages. All villages are under low and very levels of total N (Figure 24). Except for some areas in Lakhu all land are under low and very low levels of available P (Figure 25). Lands across all the six villages are also in low and very low levels of available K except for some lands in Khuruguma, Zamdongkha and Lakhu (Figure 26). Poor soil fertility and decline in supply of FYM has resorted farmers with coping mechanism of offsetting them by increasing use chemical fertilizers. Fertilizers are available at the affordable price. The marketing of agricultural produces especially chili, beans and rice have enabled the farmers with cash income to buy farm inputs. Moreover, the people employed in off-farm (25%) activity complement the cash income.

Figure 33 shows the village wise trend in use of chemical fertilizers in last five to 10 years. Except in Pakcheykha and Wolakha other villages have experienced an increased number of HH using chemical fertilizers. The number of HH using fertilizers is not as high as the HH experiencing a decline FYM availability (Figure 32). In three villages of Khuruguma, Pakcheykha and Wolakha there in no HH experiencing decreasing trend of fertilizer use.

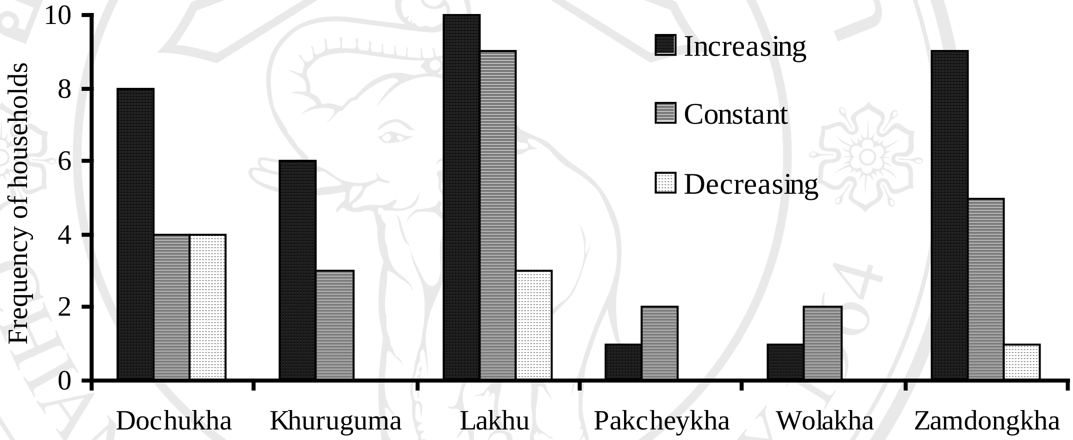

Figure 33. Village wise trends in chemical fertilizers use.
(Source: Survey, 2005).

The most important reason mentioned by each farming HH for use of fertilizers are summarized in Table 22. Thirty-seven percent of HH mentioned the use fertilizers to compensate insufficient FYM availability. Interestingly, 21% mentioned the purpose of using fertilizers was to boost crop yields so as to maximize profit and this means that the market is becoming the driving force.

Table 22. Most important reason for use of chemical fertilizers.

Most important reason for use of chemical fertilizers	% HH	Number of HH
Insufficient FYM due to decrease in cattle holding	37	28
To increase yields (when yields were constant)	21	16
Soil fertility declining	16	12
Less labor to collect livestock bedding materials	12	9
Yields of the crops declining	8	6
Other farmers using chemical fertilizers	5	4
Total	100	75

(Source: Survey, 2005).