# Distribution of Soil N, P and K of Farmland and Natural Grassland in Southwest Tibet

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Abstract: The amount and the cycling of soil Nitrogen (N), phosphorus (P), and potassium (K) are significantly affected by land use types. However, few studies determined the differences in the N, P, and K distributions in different soil layers from farmland and grassland in alpine areas. The main agricultural area of Tibet was selected to analyze the changes in total nitrogen (TN), total phosphorus (TP), total potassium (TK), available N (AN), available P (AP), and available K (AK) in farmland and adjacent natural grassland at different depths. The TN, TP, AN, AP, and AK concentrations and the N:P, N:K, and P:K ratios in farmland and grassland in the 0–50 cm layer decreased with increasing soil depth, whereas the content of TK increased. The effect on TN in soil is greater in grassland than in farmland and mainly occurs in the surface layer (0–10 cm). No obvious differences in TP were noted between the two land use types.TK in all soil layers was higher in grassland than in farmland; agricultural production was responsible for a net consumption of soil K. Soil TN is more sensitive to land use than soil TP and TK. The effect of soil surface aggregation effect on TN (0–20 cm) is greater in farmland than grassland, and no significant aggregation effect was found for TP and TK. The results can provide useful information for the estimation of soil N, P and K content in different land use types and land management in Tibet plateau.

## 1 INTRODUCTION

N, P, and K are the most important nutrients for crop production in agriculture. However, inappropriate agricultural management and land use practicescan turn these nutrients into agricultural pollution sources, hampering the development of sustainable crop production systems and adversely affecting the environment.Specifically, rapid population growth and an increasing demand for the transformation of natural ecosystems into farmlandhave caused urgent ecological and soil degradation problems(Foley et al., 2005).

Land use affects different aspects of soil nutrient cycling,such asmineralization, leaching, absorption, and fixation.For example, the conversion of grassland to farmlandhas been reported to increase the number of soil pores (Lipiec et al., 2006)and to change the soil water content and concentrations of soil nutrients(McLauchlan, 2006).This conversion also promoted mineralization of soil nutrients(Yang et al., 2008)and nutrient loss via leaching.Soil N, P, and other nutrients significantly decreased when grassland was reclaimed to farmland(Menget al., 2008). In contrast, the content of soil nutrients increased in abandoned farmland(Deng et al., 2013).

Land use affects the contents of soil nutrients mainly in the surface layer (0–20 cm). For example, the soil N(Schilling et al., 2009)and P (Lemanowiczand Krzyżaniak, 2015) contentsdecreased with increasing soil depth, whereas soil K increased with increasing soil depth(Saini and Grewal, 2014).Chaiet al. (Chai et al., 2015) found that theN and Pcontents in soil significantly decreased with increasing soil depth.Schilling et al.(Schilling et al., 2009)reported that the content of N in riverside soil in Iowa significantly decreased with increasing soil depth, butPdid not show a regular change.The proportional relationship among carbon, N, P, K, and other



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elements in soil influences and determinesthe growth of soil microorganisms(Cleveland and Liptzin, 2007; Griffiths et al., 2012) andplants, as well as the transformation of soil nutrients(Xuet al., 2015).

Tibetis characterized byhighly vulnerable ecological conditionsand is highly sensitive to global climate change.Grassland and farmland account for 66.80% and 0.42% of the total area of Tibetand represent the most important land usetypes in this region.The rapid increase of the population in Tibethas significantly changed the land use types, which raises the question: how does land use affect soil nutrient cycling in the Tibetan alpine region? In this work, our objectives were 1) to quantitatively assess how affect of land use types on N, P, K, and available N, P, K in difference depth soil; 2) to clarify soil N:P:K ratio with land use types, thus providing some useful information for land use in Tibet Plateau.

# 2 MATERIALS AND METHODS

## 2.1 Study Site

The study area was located in the southwest of the Tibetan Plateaunorth of the Himalayas and the south bank of YarlungZangbo Riverand had an average altitude of 4000 m above sea level. Annual precipitation in this region is approximately 290-430 mm with potential evaporation of approximately 2249.6 mm.

The main crops in this region are spring barley and maize, harvested once per year with a growing season spanning April to October. After the harvest, most of the straw is used as feedstock for livestock.The average fertilization amount has been increasing;Tibetan statistical data indicate that the fertilization amount was 108 kg/ha in 2000 and 163 kg/ha in 2012 for Shigatseregion. An imbalanced fertilizer supply in Tibet agricultural management for $N:P_2O_5:K_2O$was approximately 7:4:1 for 2012 and 129:73:1 for 2000. The average yields were approximately 4t.ha$^{-1}$for spring barley and 4.5 t/ha for winter wheat(Paltridgeet al., 200). The soil is characterized by a high sand/clay ratio and is rich in gravel, a low organic matter contents (SOC of 3.19–14.4g.kg$^{-1}$), and pH of 8.1–9.0(Zhonget al., 2005).In April 2014, we selected a field in a contiguous area greater than 2 hm$^2$ with a centralized farmland and reclamation period of more than 50 years. We selected 8 sampling areas were established from Bailang, Gyangze, Xietongmen, Shigatse, Namling, Qushui in southwest Tibet (Table 1). We selected two sampling areas from Bailang and Gyangze respectively, and one sampling area was selected in others different area. Three sampling points were then randomly selected from each sampling area and as replicates for each study area. The research layers included topsoil (0-30cm) and the plow pan (~50 cm), and we hypothesized that land use affected the soil properties mainly in the topsoil. Soil samples were collected from the 0-5, 5-10, 10-20, 20-30, 30-40, and 40-50 cm layers. The natural grassland adjacent to each farmland was also selected for comparison for each sampling area.After removing roots, stones, and other non-soil constituents, a fresh soil sample was obtained using the method of quartering for the determinations of the AN (included ammonium and nitrate nitrogen) . Another portion of the soil was air dried and sieving through a 0.25mm mesh sieve for soil TN, TP, TK, AP and AK measurements.The semi-micro Kjeldahl method was used to determine TN(Bao,1999).Soil nitrate N and ammonium N were extracted using 2 mol.L$^{-1}$KCl and determined with a continuous flow analyzer (AA3HR, German SEAL). Fresh soil (10 g) was weighed and shaken in a 2mol.L$^{-1}$KCl solution (50 mL)for1 h and then filtered. The TP and AP contentsweredetermined witha colorimetric method, and the TK content was determined by dissolvingin $HNO_3$, $HClO_4$ and HF, and the AK content was extracted with 1 M $NH_4OAC$. TKand AK were measured with a flame photometer.

Table 1:Description of sampling areas.

| Sample region | latitude | Longitude | Elevation/m | Soil type | soil texture |
|---|---|---|---|---|---|
| Gyangze | 28°55′N | 89°39′E | 4088 | Subalpine steppe soil | Sandy loam |
| Bailang | 29°09′N | 89°13′E | 3886 | Subalpine steppe soil | Sandy loam |
| Xietongmen | 29°19′N | 88°22′E | 3893 | Subalpine steppe soil | Loam sand |
| Shigatse | 29°21′N | 88°50′E | 3842 | Subalpine steppe soil | Sandy loam |
| Namling | 29°61′N | 89°06′E | 3835 | Subalpine steppe soil | Sandy loam |
| Qushui | 29°22′N | 90°51′E | 3594 | Yellow brown soil | Sandy clay |

## 2.2 Statistics

The differences in soil nutrients (TN, TP, TK and AN, AP, AK) in the different soil layers of grassland and farmland were analyzed by one-way analysis of variance (ANOVA) and the LSD method usingSPSS 20.0 (IBM, USA) statistical analysis software， andtreatments were considered significantly different at $\alpha<0.05$. The figures were constructed using Origin 9.0 (OriginlabCorporation, USA).Data variability was evaluated using the coefficient of variation (CV), as shown in equation 1 below:

$$CV=\text{Standard deviation (SD)}/\text{mean} \times 100\% \quad (1)$$

# 3 RESULTS AND ANALYSIS

## 3.1 Distribution Characteristics of Soil N

### 3.1.1 Soil TN Concentration

The soil TN and ANconcentrations in farmland and grassland decreased with increasing soil depth (Figure 1a).The soil TN concentration in farmland decreasedby 45.45% from 0.55 g·kg$^{-1}$in the 0–5 cmsurface layer to 0.30 g·kg$^{-1}$in the 40–50 cm layer.In the 0–50 cm layer, the vertical spatial CV of the soil TN concentrationwas 21.30%.Vertical variability was mainly reflected in the 0-20 cm layer.The soil TN decreased by 41.18% from 0.51 g·kg$^{-1}$ in the 10–20 cm layer to 0.30 g·kg$^{-1}$in the 40–50 cm layer, with a CV of 22.65%.This result indicates that farmland soil TN is mainly concentrated inthe 0–20 cm surface layerand rapidly decreases with increasing soil depth.

The soil TN concentration in grassland decreased by 63.16% from 0.76 g·kg$^{-1}$ in the 0–5 cm layer to 0.28 g·kg$^{-1}$ in the 40–50 cm layer.The vertical coefficient of spatial variation was 37.15%, and vertical variability was mainly reflected in the 0–20 cm layer.The soil TN concentration in the 0–10 cm layer was higher in grassland than in farmland.The difference between the two land use types in the 0–5 cm layer was highly significant ($P < 0.01$), that is, the soil TN showed a significant surface aggregation effect under the effect of plant roots in grassland.The soil TN concentration was higher in grassland than in farmland below the 10 cm layer, but was not significant.In the 40–50 cm layer, the soil TN concentration in grassland was 7.71% higher than in farmland.In all of the layers below 10 cm, the difference in the soil TN concentration between grassland and farmlanddecreased with increasing soil depth.

### 3.1.2 Soil ANConcentration

Figure 1b shows that the soil AN concentrations in farmland and grassland significantly decreased with increasing soil depth.The declining trend in farmland was more highly significant than in grassland.The CV of farmland was 51.85% andwasrelatively smalleringrassland,where the CVwas 31.12%.

The farmland soil AN decreased by 68.13% from 37.87mg.kg$^{-1}$ in the 0–5 cm layer to 12.07mg.kg$^{-1}$in the 40–50 cm layer.The decrease from 0–5 cm to 5–10 cm was the most highly significant, and the difference between the two layers was significant.This resultindicates that soil N mineralizationis mainly concentrated in the 0–5 cm surface layer.The soil N mineralization conditions gradually worsened with increasing soil depth, leading to a significant decrease inthe mineral N content.Meanwhile, the tillage disturbance was mainly present in the 0–20 cm surface layer.The soil aeration and temperature werelowerin the layers below 20 cm.Consequently, the soil ANconcentration was also lower in deeper layers.

The grassland soil ANconcentration was 11.47 mg.kg$^{-1}$in the 0–5 cm layer and 5.66 mg.kg$^{-1}$in 40–50 cm layer.The vertical spatial variability was smaller in grassland than in farmland.The soil AN concentration in the 0–5 cm layer was significantly different from that in the other layers($P<0.05$).However, the soil AN concentration in the layers below 20 cm showed no significant differences from theother layers, that is, the N mineralization conditions in the layers below 20 cm wererelatively consistent.

The soil AN concentrationwas higher in farmland than in grassland in all soil layers, especially in the 0–10 cm layer.This result may be becauseinorganic fertilizer applicationand farmland cultivation promoting soil N mineralization.The differences in the soil ANconcentration between farmland and grassland were significant forthe 0–5 and 5–10 cmlayers.The difference in the soil AN concentration between farmland and grassland gradually decreased with increasing soil depth.In the 0–5 cm layer, the soil AN concentration in farmland was 26.40mg.kg$^{-1}$ higher than in grassland, and in the 40–50 cm layer, that was only 6.41 mg.kg$^{-1}$.

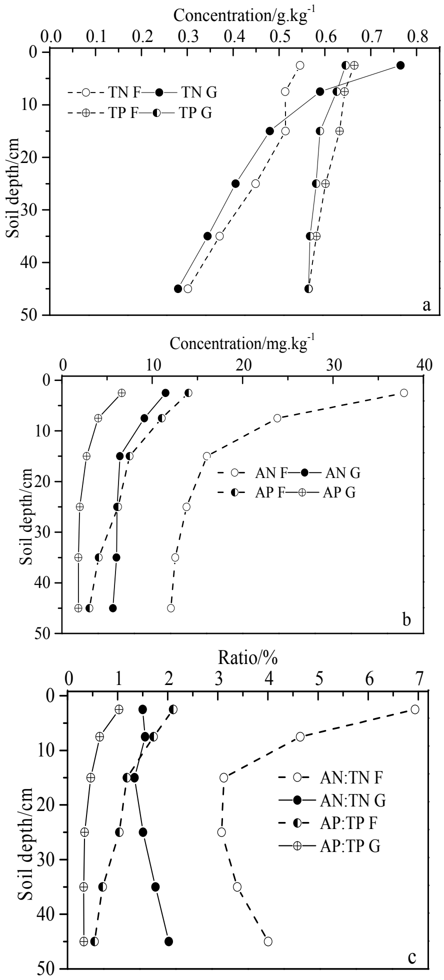


Figure 1: Variation soil TN, TP and AN, AP concentrations of farmland and grassland with soil depth.

Note: F and G means farmland and grassland respectively.

### 3.1.3 AN:TNRatio

The AN:TN ratio is shown inFigure 1c.The soil AN:TN ratio in all farmland layers was significantly higher than in grassland.TheAN to TN ratioranged from 1.34 to 2.02 % in grassland and from 3.07% to 6.94% in farmland.

In the 0–20 cm layer, the AN to TN ratio in farmland and grassland decreased with increasing soil depth.In the layers below 20 cm, the ratio increased with increasing soil depth, but the increase was not significant.In the 0–20 cm layer in farmland, the AN to TN ratiodecreased from 6.94% (0–5 cm) to 3.12% (10–20 cm).In the layers below20 cm, the AN to TN ratio gradually increased.The AN to TN ratiowas 4.01% in the 40–50 cm layer.In the 0–20 cm layer in grassland, the AN to TN ratio decreased from 1.50% (0–5 cm) to 1.34% (10–20 cm).In the layers below 20 cm, the AN to TN ratiowas 2.02% in the 40–50 cm layer with increasing soil depth.

## 3.2 Characteristics of the Distribution of Soil P

### 3.2.1 Soil TPConcentration

The soil TP concentration in farmland and grassland decreased with increasing soil depth (Figure 1a).The soil TP concentration in farmland was 0.66 g.kg$^{-1}$in the 0–5 cm layer.In the 40–50 cm layer, the soil TP concentration decreased by 12.12% to 0.58 g.kg$^{-1}$.The soil profile TP concentration variability was less, with a CV of 6.23%.The soil TP concentration in grassland was 0.65 g.kg$^{-1}$ in the 0–5 cm layer. In the 40–50 cm layer, the soil TP concentration decreased by 13.85% to0.56 g.kg$^{-1}$.The variability of the TP concentration in the soil profile was less, with a CV of 5.50%.The soil TP concentrationwas higher in farmland than in grassland in all soil layers.The differences between the two land use types decreased with increasing soil depth. In the 40–50 cm layer, the soil TP concentration in farmland and grassland was nearly equal.In other words, the soil TP concentration in farmland was mainly affected by fertilizer application, which increased the soil P concentration in the surface layer.

### 3.2.2 Soil AP Concentration

The soil AP concentration decreased with increasing soil depth(Figure 1b).The declining trend in farmland was more significant than grassland, i.e.,from 14.01 mg.kg$^{-1}$in the 0–5 cm layer to 3.04 mg.kg$^{-1}$ in the 40–50 cm layer, the CV was 54.89%.The decrease in the soil AP concentration was most highly significant in the 0–20 cm layer.In the grassland soil profile, the CV of the AP concentration was 59.54%.Vertical variability was mainly observed in the 0–20 cm layer.In the layers below 20 cm, the variation in the soil AP concentration was less, with a CV of 4.59%.

### 3.2.3 Soil AP:TP Ratio

The soil AP to TP ratio in farmland and grassland decreased with increasing soil depth (Figure 1c).The soil AP to TP ratio in farmland was significantly higher than in grassland.The 95% confidence intervals were (1.04–2.02)% and (0.44–0.62)%, mainly because the application of chemical P fertilizer in farmland increased the AP concentration and farmland cultivation promoted P mineralization.The soil AP to TP ratio in the 0–5 cm surface layer in grassland was 1.03% and decreased to 0.32% in the 40–50 cm layer.In farmland, the soil AP to TP ratio in the 0–5 cm surface layerwas 2.11% and decreased to 0.54% in the 40–50 cm layer.

## 3.3 Distribution Characteristics of Soil K Concentration

### 3.3.1 Soil TK Concentration

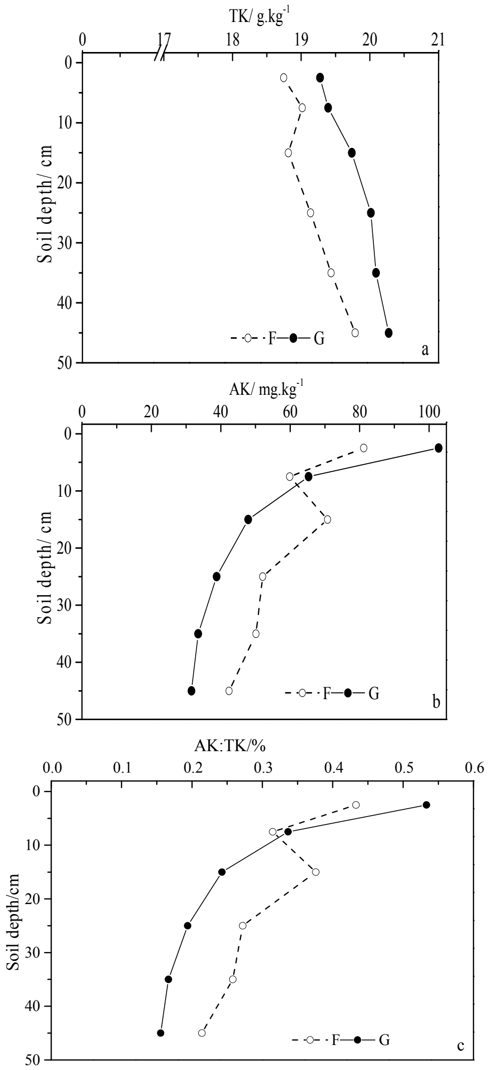


Figure 2: Variation of soil TK and AK concentrations of farmland and grassland with soil depth.

The soil TK concentration in farmland and grassland slightly increased with increasing soil depth(Figure2a).The CV of the soil profilein farmland and grassland was 2.07% and 2.02%, respectively.The soil TK concentration was higher in grassland than in farmlandin all soil layers.In the 0–50 cm layer, the soil TK concentration range was 17.95–20.36 g.kg$^{-1}$in farmland and 18.70–20.90 g.kg$^{-1}$ in grassland.In farmland, the soil TK concentration was 18.75 g kg$^{-1}$in the 0–5 cm layerand 19.79 g.kg$^{-1}$in the 40–50 cm layer, an increase of 5.55%.The soil TK concentration in grassland was 19.28 g.kg$^{-1}$ in the 0–5 cm layer and 20.26 g.kg$^{-1}$in the 40–50 cm layer, an increase of 5.08%.

### 3.3.2 Soil AK Concentration

The soil AK concentration decreased with increasing soil depth (Figure 2b).The soil AK concentrationdecreasedby 69.30%from 102.77 mg.kg$^{-1}$ (0–5 cm) to 31.55 mg. kg$^{-1}$ (40–50 cm) in grassland.The CV of the verticalprofile was 51.01%.The soil AK concentration in farmlanddecreased by 47.78% from 81.17 mg.kg$^{-1}$ (0–5 cm) to 42.39 mg.kg$^{-1}$ (40–50 cm), and the CVwas 24.18%.

The 95% confidence interval for the soil AK concentration was 49.10–69.69 mg.kg$^{-1}$ in farmland and44.12–65.98 mg.kg$^{-1}$ in grassland.In the0–5 and 5–10 cm soil layers, the soil AK concentrationwas higher in grassland than in farmland.In the layers below 10 cm, the soil AK concentration was higher in farmland than in grassland.In other words, the net consumption of the soil AK is reflected in the 0–10 cm surface layer in farmland.

### 3.3.3 Soil AK:TK Ratio

The AK:TK ratio was higher in farmland than grassland (Figure 2c).The 95% confidence interval for the soil AK:TKwas (0.26–0.45)% in farmland and (0.21–0.38)% in grassland.The farmland soil AK:TK ratio decreased with increasing soil depth.The ratio was 0.43% in the 0–5 cm layer and 0.21% in the 40–50 cm layer. The soil AK:TK vertical spatial variability was less in farmland than in grassland, with a CV of 26.02% in farmland and 53.13% in grassland. The soil AK:TK ratio was 0.53% in the 0–5 cm layer and 0.16% in the 40–50 cm layer in grassland.

### 3.4 Proportion Characteristics of Soil N, P, and K

A proportion analysis of soil N, P, and Kshowed that the N:P, N:K, and P:K ratios decreased with increasing soil depth (Figure3).Of these ratios, P:Kshowed the lowest change amplitude.In other words, soil P and K maintaineda similar change rate in the profile.The declining rate of soil N was higher than that of P and K, indicating that soil Nresponds most sensitively to changesinthe land use type.

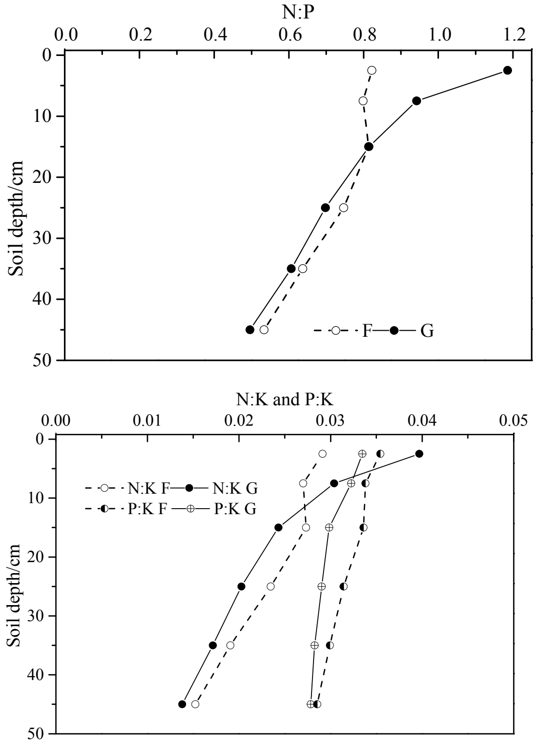


Figure3: Variation of the ratio of soil N:P,N:K and P:K with soil depth.

The soil N:P ratio decreased from 1.19 to 0.50 in grassland and from 0.82 to 0.53 in farmland.The spatialvariability of the N:P ratio in the soil profile in grassland was significantly higher than in farmland.The CV of soil N:P in grassland and farmland was 31.45% and 16.01%, respectively.

The soil N:K ratio in grassland decreased by 75.0% from 0.04 in the 0–5 cm layer to 0.01 in the 40–50 cm layer,and the CVwas 39.2%.The vertical spatial variation of the soil N:K ratio in farmland was less than in grassland, with a CV is 23.0%.The soil N:K ratio in farmland decreased by 50% from 0.03 in the 0–5 cm layer to 0.015 in the 40–50 cm layer.

Thesoil P:K ratio vertical variation was lower in the 0–50 cm layer, with a CVof8.13% and 7.54% in grassland and farmland, respectively.The soil P:K ratio in farmland decreased by 20%from 0.035 in the 0–5 cm layer to 0.028 in the 40–50 cm layer, whereas that in grassland decreased by 15.15% from 0.033 in the 0–5 cm layer to 0.028 in the 40–50 cm layer.

## 4 DISCUSSION

### 4.1 Significant Surface Aggregation of Soil N and P

The soil N and P concentrations decreased with increasing soil depth (Schilling et al., 2009; Xionget al., 2014).However, the increase insoil K with increasing soil depth(Saini and Grewal, 2014; Natarajan and Renukadevi, 2003)may be related to K absorptionby surface plants.

On aglobal scale, the soil TN concentration is in the range of 0.29–18.20 g.kg$^{-1}$(Cleveland and Liptzin, 2007).In the present study, the soil TN concentrations in farmland and grassland were lower.Moreover, the soil TN wasconcentrated in the 0–10 cm surface layer.The soil TN concentration in farmland and grassland in the 0–10 cm layer was1.22 and 1.55 times that in the 0–50 cm layer.The soil TN concentrationin farmland and grassland in the 0–20 cm layerwas1.21 and 1.32 timesthat in the 0–50 cm layer, respectively.This result isconsistent with the findings of Yang et al.(Yang et al., 2010)for the Qinghai–Tibet Plateau.In the present study, the soil N was mainly concentrated in the 0–20 cm layer.The soil P concentration in farmland and grassland in the 0–10 cm layerwas1.07 and 1.08 times that in the 0–50 cm layer, respectively,indicating that soil N experiences a stronger surface aggregation effect than soil P in the study area.This finding contradicts the result of JobbÁgy and Jackson(JobbÁgy and Jackson, 2001), who showed that the soil TP (0–20 cm/100 cm=48.9%) exerteda stronger surface aggregation effect than the soil TN (38.21%).This discrepancy may be related to the selective absorption of the elements by different vegetation types. Highland barley, rape, and grassland vegetation have a higher demand for soil N than P; thus, N is concentrated in plant roots. Meanwhile, the massive application of N fertilizer increases the soil N concentration inthe surface layer.

The soil TN concentration in the 0–20 cm surface layer was higher in farmland than in grassland(Wang et al., 2009).In the 0–10 cm layer, the soil TN concentration in grassland is higher than in farmland.In the layers below 10 cm, the soil TN concentrationwashigherin farmland than in grasslandbecause the soil in the study area was sandy, with a poor adsorption capacity for soil N fertilizer in the surface layer.The addition of N fertilizer in agricultural production can increase the soil TN concentration, but the leaching of N causes the soil TN in the 0–10 cm surface layer not to be significantly higher than in grassland. Land cultivation and management promote the maturation of soil and the mineralization decomposition of soil N, inducing the loss of N, causing the soil N concentration in the surface layer in farmland to be lower than in grassland.

The soil AN contents and AN to TN ratio determine the intensity of the supply of soil N(Penget al., 2013) and its loss potential.In this study, the soil AN contents and the AN to TN ratio in the 0–50 cm layerwerehigher in farmland than in grassland, particularly in the 0–20 cm layer.This result is related to the increase in soil AN after the application of chemical N fertilizer and the promotion of soil N mineralization after farmland cultivation.Soil AN accounts for the highest proportion in the 0–5 cm layer in farmland and grasslandbecause the soil in the surface layer hasbetter aeration as well aswater and heat conditions (Malhi and O'sullivan, 199), which promote soil N mineralization(Sun et al., 2013; Schüttet al., 2014).In the layers below 20 cm, the AN to TN ratio increases, possibly because the soil AN in the upperlayer is easily leached due to rainfall.Thus, the N in the 0–20 cm surface layer migrates to the deeper layer and gradually accumulates, increasing the proportionof the soil AN in the deeper layer.The AN to TN ratio in farmland was higher than that in grassland(Yang et al., 2008).On the one hand, this is related to the application of N fertilizer in agricultural production.On the other hand, farmland soil had ahigher N mineralization rate than grassland soil (Chen et al., 2014).Plant root exudate influences soil mineralization.The plant root system in farmland has a higher biomass than in grassland.The exudates produced during the growth of the root system promoted the mineralization of soil N(Herman et al., 2006; Landi L et al., 2006)and improvedthe soil inorganic N concentration and the AN to TN ratio.

## 4.2 Net K Consumption in Farmland Soil

K is anelemental nutrient that is easy to neglected, including its reserve, distribution, effectiveness, and influencing factors(Sardans and Peñuelas, 2015).However, K is an important limiting nutrient for plant growth(Hoosbeeket al.,2002).This study result about soil TK was consistent with Liu et al (Liu et al.,2005), that the average contents of TK in the surface layer of Tibet was 17.7–23.4 g.kg$^{-1}$.The TK concentration in all soil layers was higher in grassland than in farmland.A farmland ecosystem exerts anet consumption effect on soil K.In the study area, the main agricultural crops are highland barley and rape.These two crops must maintainhigh K consumption to support theirgrowth and development.For example, the consumption ratio of N, P,and K for rape is usually 1:0.38:0.94(Sun et al., 2002).Therefore, if K cannot be supplemented in a timely manner, it is shownin the net consumption.The study result suggests that K fertilizer should be properly supplied to local agricultural production to decrease K consumption and prevent a reduction in soil productivity.

The soil K concentration decreased with increasing soil depth because this element is more easily leached to the deeper soil layer than N and P(Nandwalet al., 1998).In addition, K in the surface layer is likely to leach with water runoff (Barréet al., 2009).Plant roots mainly occur in the 0–20 cm layer.K absorption by plants promotes the reduction of soil K at the surface, therebyleading to a higher K concentration in the lower layers.The soil AK concentration in the 0–10 cm layerwas higher in grassland than farmland, whereas that in the layers below 10 cm were higher infarmland than grassland, possibly because of the migration of soil AK to the deeper layers because of farmland cultivation.

## 4.3 The Vertical Variability of Soil N IsHigher than that of Soil P and K

The vertical variability of soil N, P, and K in the 0–50 cm layer of farmland and grassland follows the order TN>TP>TK.The CV of the soil N, P, and K concentrationwas 21.3%, 6.23%, and 2.07% in farmland,and 37.15%, 5.5%, and 2.02% in grassland, respectively.In other words, soil N has a greater spatial variability in the vertical profile of farmland and grassland, which is mainly reflected in the 0–20 cm surface layer.The soil N has a strong activity, and N fertilizeris usually applied in regional farmland, causing the N concentration in the surface layer to greatly increase,improving the spatial variability in the vertical profile.Data from 2013 show thatthe amount of N, P, and K fertilizerconsumed in Shigatsewas 8106, 4733, and 1084 t, respectively(Tibetan statistics bureau, 2013), indicating that N and P fertilizers were preferably applied over K fertilizer.

### 4.4 The Loss of Soil N is Greater than that of Soil P and K

The proportioncharacteristics show changes in theamount of the soil elementsat different depths and the sensitivity of the response to land use patterns.The proportionvalues of soil N:P, N:K, and P:K decreased with increasing soil depth, consistent with the findings of Luo et al.(Luoet al.,2012)for an alpine meadow.The declining trends of N:K and N:P were significant.In other words, the declining trend of soil N with increasing soil depth was significantly higher than that of soil P and K.

The results showed that the soil N:P values in farmland and grassland were lower than the Chinese nationalscale (5.2)(Tianet al., 2010)and the global average value(13.1±0.8)(Cleveland and Liptzin, 2007), consistent with studies by Zhu et al. (Zhu et al.,2013)in the forest and grass gully regions of the Loess Plateau (0.86), by Zhong et al.(Zhonget al., 2005) in theShigatse agriculture area of Tibet and by Wei et al.(Wei et al., 2012)in a Lhasa farmland (1.87).Thus, in alpine ecosystems, the soil N concentration is low, the P concentration is relatively high, and the soil N:P value is low.

The soil TP:TKratio was in the range of 0.025 to 0.035, which is close to the average level of 0.044in the surface soil of Tibet obtained by Liu et al.(Liu et al.,2005) and consistent with the results of Wei et al. (Wei et al., 2012)for a Northern Tibet Grassland (0.034) and Zhu et al.(Zhu et al.,2013) for the gully region of the Loess Plateau (0.03), indicating that the spatial variability of soil P:K in different regions is relatively small.

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