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Fertilizer Practices Affecting Soil Nutrient Status of Apple Orchards in Bhutan

Tshering[1,2], Unaroj Boonprakob[2]* and Kumut Sangkhasila[3]

ABSTRACT

Apple (*Malus domestica* Borkh.) is one of the important fruit crops in Bhutan. However, little information is available on orchard nutrient status. This study aimed to evaluate the soil nutrient status resulting from different fertilizer practices in apple orchards. Three major apple growing districts (Thimphu, Paro and Haa) and three common fertilizer practices (organic, inorganic and mixed) were surveyed. In each district, 10 to 12 orchards were selected and six to seven trees per orchard randomly marked for soil nutrient evaluation. Soil samples were collected in December 2009 (during dormancy) from two depths (0–20 and 21–40 cm). Chemical analyses were carried out in the Soil and Plant Analytical Laboratory, Bhutan for pH, N, P, K, Ca, Mg, organic carbon and cation exchange capacity (CEC). Results showed that the apple orchards had low pH (5.65–5.85) in the inorganic fertilizing practice, low nitrogen (0.05–0.18%) in all fertilizer practices and moderate to high (17.7–86.75 mg kg^{-1}) available phosphorous (P) in the inorganic fertilizing practice. The pH level was significantly different between fertilizer practices. No significant difference was observed for P and exchangeable Ca among districts, between fertilizer practices within a district and between soil depths within fertilizer practices. Significant differences were found between districts for N, organic C and CEC. In addition, the results showed significant differences in the nutrient status of N, P, K, Ca, Mg and CEC between the two soil depths; the surface soil (0–20 cm) always contained the higher amount. The results revealed that there was an insufficient level of N in all Bhutanese apple orchards, while the levels of available P and K were in the sufficient range. Fertilizer practices had insignificant results on soil nutrient contents. Orchards under inorganic fertilizer had a lower pH than the optimum range. The study also indicated that collecting soil samples from two depths is necessary to analyze the nutrient content in Bhutanese apple orchards.

Keywords: apple, Bhutan, district, fertilizer practices, soil nutrient

INTRODUCTION

Bhutan is a mountainous and landlocked country situated between N 26°40′ to 28°15′ and E 88°45′ to 92°10′, encompassing 38,394 sq km (National Statistics Bureau, 2009). The elevation ranges from less than 140 m in the Sub-Himalaya in the south to more than 7,000 m in the Great

1 Renewable Natural Resources Research and Development Centre, Department of Forest and Park Services, Ministry of Agriculture and Forest, Thimphu, Bhutan.

2 Department of Horticulture, Faculty of Agriculture, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand.

3 Department of Soil Science, Faculty of Agriculture, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand.

* Corresponding author, e-mail: unaroj.b@ku.ac.th

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Himalaya in the north (Okazaki, 1987). The country is divided into six agro-ecological zones. The country's total population is about 671,000 (National Statistics Bureau, 2009) and 69% of the population lives in rural communities depending on agricultural farming (Office of the Census Commissioner, 2005). Among the fruit crops, apple is considered as an important cash crop and is comparable with mandarin in terms of area and production.

The apples are cultivated in the warm and cool temperate regions where the average daily temperature varies from 5 °C in January to 25 °C in July. Annual production was reported to be about 7,070 tonnes from a production area of 1,390 ha located mainly in western and central Bhutan (Department of Agriculture, 2007). 'Red Delicious' and 'Royal Delicious' are the main commercial cultivars and are grown on over 80% of the area under apples. The shortcomings of these varieties were reported to be low yield, poor fruit quality, alternate bearing, nutritional disorder, poor fruit set, high sensitivity to fluctuating temperature (particularly during flowering) and greater distance of fruiting branches from the tree trunk ultimately reducing the yield per unit area (Sharma and Karkara, 2004). Most orchards are located on slopes. The soil is marginal and has poor nutritional status. Growing fruit on sloping areas presents many production problems, especially regarding mineral nutrition, which has a great effect on tree growth and productivity. The loss of nutrient through runoff or leaching is excessive, especially in areas having high rainfall (Verma *et al.,* 2005).

The soil nutrient may vary from orchard to orchard. For suitable applications of fertilizers, soil and plant analyses are helpful guides. However, many orchard owners ignore these analyses and practice a blanket annual fertilizer application which might lead to a nutrient imbalance. In addition, about 40% of the growers depend only on farmyard manure (Department of Agriculture, 2008) because it is readily available and inexpensive compared to chemical fertilizers. Furthermore, knowledge on nutrient status would help the growers to correct any nutrient imbalance and improve the yield and quality of the apple crop in general.

An apple nutrition study has not been undertaken in Bhutan and very little relevant information is available currently. The study by Tamang *et al.* (2001) was the only information found on apple nutrition in Bhutan. Moreover, environmental differences among locations limit any generalization of available nutrition information. The objective of this study was to evaluate the fertilizer practices affecting soil nutrient status and to compare nutrient levels from two soil depths in orchards growing the apple cultivars 'Red Delicious' and 'Royal Delicious' in Bhutan.

MATERIALS AND METHODS

The study area and methods

The three major apple growing districts in Bhutan (Thimphu, Paro and Haa) are located from the warm temperate zone (Thimphu and Paro) with an altitude range of about 1,800–2,600 m above sea level (asl), to the cool temperate zone (Haa) with an altitude range of about 2,600–3,600 m asl. The study sites were located by a global positioning system and the locations are shown in Figure 1. The mean minimum and maximum temperatures are 0.1° and 26.3 °C for Thimphu and Paro and 0.1° and 22.3 °C for Haa, respectively. The annual precipitation is 650–850 mm.

The study was carried out using three fertilizer application practices: organic (use of farmyard manure), inorganic (use of chemical fertilizer) and mixed (use of farmyard manure and chemical fertilizer) with commercial 'Red Delicious' and 'Royal Delicious' apple trees. In total, 32 orchards were studied. At Thimphu, 10 orchards were sampled consisting of four organic,

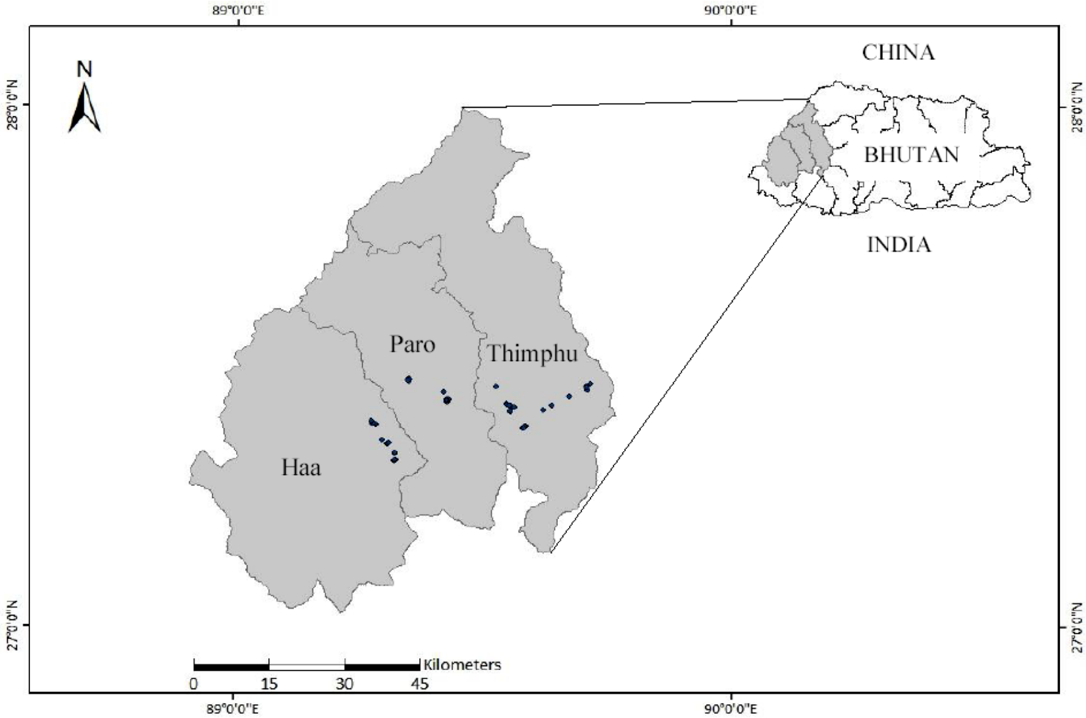

Figure 1 Bhutan map showing the location of study sites (•) in three main apple growing areas.

four inorganic and two mixed fertilizer applications. At Paro, the 10 sampled orchards consisted of two organic, three inorganic and five mixed fertilizer applications. At Haa, the 12 sampled orchards consisted of five organic and seven mixed fertilizer applications; no inorganic practices were available for observation.

Traditionally, apple growers use farmyard manure (FYM) from their own farms that is composted from a mixture of cow dung and leaf litter in the apple orchard. In general, for each apple tree, about 7–15 kg of FYM is applied annually (Table 1). Fertilizers like urea (46% N), suphala (15:15:15 of N-P-K), single superphosphate (16% P_2O_5) and muriate of potash (60% K_2O) are the common inorganic fertilizers use in apple orchards. About 0.2–1.5 kg per tree of inorganic fertilizer mixture is applied annually (Table 1). Fertilizers are broadcast under the tree canopy area during December to March. Small- and medium-scale apple orchards with less than 200 trees aged between 10 and 20 y were selected. Six to seven

Table 1 Annual amount of fertilizer used by apple growers in three districts in Bhutan.

Fertilizer	Annual amount (kg/tree)		
	Thimphu	Paro	Haa
FYM	7.00–15.00	7.50–5.00	7.50–5.00
Urea (46%)	0.25– 0.50	0.15–0.30	0.10–0.60
Suphula (15:15:15 N-P-K)	0.25–0.65	0.15–0.30	0.10–0.25
Single superphosphate (16% P_2O_5)	0.30–0.35	0.20–0.25	0.10–0.20
Muriate of potash (60% K_2O)	0.30–0.35	0	0

FYM = Farmyard manure.

trees per orchard were randomly sampled. Soil samples at two depths (0–20 and 21–40 cm) were collected during tree dormancy (December 2009).

Soil sampling and analytical methods

In each orchard, two composite soil samples (surface soil and subsoil at 0–20 and 21–40 cm depth, respectively) were collected from soil within the area defined by the tree canopy of the selected trees using a stainless steel soil auger (Holland *et al*., 1967; Soil Fertility Unit, 2008). The analyses were based on standard methods (Black *et al*., 1965) used by the Soil and Plant Analysis Laboratory (SPAL), Bhutan. The samples were air dried and sieved using a 2 mm mesh size. The soil pH was determined in a 1:1 soil water suspension using an automatic pH meter (PHM 83, Denmark). Organic carbon (OC) was measured by the Walkley and Black oxidation method (Black *et al*., 1965). Total nitrogen (N) was extracted and converted into an ammonium form by micro-Kjeldahl digestion with H_2SO_4 and a Se-based catalyst and colorimetry. The exchangeable cations (Ca and Mg) were determined by leaching with excess 1M ammonium acetate (pH 7) and the extract measured in an atomic absorption spectrophotometer (PU 901, Unicam, Cambridge, UK). The cation exchange capacity (CEC) was determined by leaching the ammonium with excess 1M KCl and the ammonium in this extract was determined by colorimetry using a segmented flow analyzer (Skalar 4000, The Netherlands). The available P was determined by 0.5M HCl and 1M NH_4F extraction and colorimetry. The available K was extracted from a 5 g sample by mixing with 50 mL of 0.01 M $CaCl_2$ solution and then shaking for 120 min at 200 rpm followed by filtration. The final extracts were measured in the segmented flow analyzer with a flame photometer. The fertility status was categorized as very high, high, moderate, low or very low based on criteria suggested by interpretation of the soil analytical data (Soil Survey Unit, 2010).

Statistical analysis

The study was conducted using a three factor nested design, where the fertilizer practices were nested in districts while the soil depths were nested in the fertilizer practices. The data were subjected to analysis of variance using a general linear model. A two- sample paired t-test was used to compare the nutrient differences between the surface soil (0–20 cm) and the subsoil (21–40 cm). Statistical significance was tested at the 0.05 level and high significance at the 0.01 level.

RESULTS

Nutrient levels among two soil depth

The pH and nutrient contents (N, P, K, OC, exchangeable Ca, Mg and CEC) were compared using the differences between samples from the surface soil (0–20 cm) and the subsoil (21–40 cm) depth (Table 2). The results showed the pH was similar but there were highly significant differences in the levels of N, P, K, OC, exchangeable Ca, Mg and CEC, with the surface soil samples having the higher values (Table 2).

Variation in soil nutrients between districts and fertilizer practices

The soil nutrient status evaluation at the two depths with the three fertilizer practices from the three districts showed that the lowest pH (5.71) occurred in the inorganic orchards at Paro and the highest pH (6.61) was in the organic orchards at Thimphu (Table 3). There were significant differences in pH between fertilizer practices within a district with the organic fertilizers being higher (pH = 6.22) than the inorganic (pH = 5.76). The pH was relatively similar at both depths sampled (Table 3).

The highest soil N level (0.14 %) was found in inorganic fertilizer practices at Paro in the 0–20 cm soil layer and the lowest N level (0.05%) was also recorded at Paro in the 21–40 cm soil layer for both organic and inorganic

Table 2 Nutrient contents of surface soil and subsoil and their differences evaluated in the dormant season (December 2009) from 32 apple orchards located in Thimphu, Paro and Haa districts of Bhutan.

Variable	Soil depth (cm) 0–20	21–40	Mean differences[1/]	*P*-value[2/]
pH (H_2O)	6.02	6.04	-0.02 ± 0.23	0.68
Total N (%)	0.14	0.08	0.06 ± 0.04	< 0.01
Available P (mg kg^{-1})	49.40	26.63	22.78 ± 28.20	< 0.01
Available K (mg kg^{-1})	132.80	88.45	44.35 ± 57.22	< 0.01
Organic C (%)	2.43	1.32	1.11 ± 0.57	< 0.01
Exchangeable Ca (mmol kg^{-1})	83.81	56.97	26.84 ± 24.63	< 0.01
Exchangeable Mg (mmol kg^{-1})	16.20	12.09	4.11 ± 6.63	< 0.01
CEC (mmol kg^{-1})	131.89	96.63	35.26 ± 30.43	< 0.01

[1/]mean ± SD; n = 32.

[2/] Probability of paired t-test.

Table 3 Nutrient levels of three fertilizer practices from three districts sampled at two soil depths evaluated in the dormant season (December 2009).

District	Fertilizer practice	Soil depth (cm)	pH (H_2O)	N (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})	OC (%)	Exchangeable Ca (mmol kg^{-1})	Exchangeable Mg (mmol kg^{-1})	Exchangeable CEC (mmol kg^{-1})
Thimphu	Organic	0–20	6.59	0.12	53.18	141.53	2.38	130.5	27.8	142.6
	Inorganic		5.84	0.13	86.75	217.67	2.73	79.6	12.8	167.7
	Mixed		6.14	0.11	57.86	116.77	2.30	87.1	16.4	174.6
	Organic	21–40	6.61	0.07	33.84	86.81	1.53	103.9	21.8	125.2
	Inorganic		5.85	0.07	57.84	135.52	1.35	53.3	9.9	130.4
	Mixed		6.23	0.07	7.74	71.30	1.00	60.1	11.4	127.1
Paro	Organic	0–20	6.11	0.07	32.40	138.23	1.70	65.1	10.6	119.7
	Inorganic		5.65	0.14	68.85	153.31	1.93	59.2	11.0	120.6
	Mixed		5.86	0.12	26.26	97.02	2.04	62.1	13.4	131.2
	Organic	21–40	6.13	0.05	17.51	101.69	1.05	45.4	7.0	110.8
	Inorganic		5.71	0.05	17.67	111.15	0.83	40.7	8.4	98.7
	Mixed		5.81	0.07	6.73	76.75	1.00	51.8	15.3	109.5
Haa	Organic	0–20	6.01	0.18	25.30	144.85	2.98	70.8	14.9	96.5
	Mixed		6.01	0.15	53.77	90.50	2.63	99.3	18.3	127.2
	Organic	21–40	5.89	0.08	13.66	61.93	1.37	33.9	7.1	45.8
	Mixed		6.14	0.10	39.98	81.19	1.74	61.8	12.3	81.6

OC = Organic carbon; CEC = Cation exchange capacity.

practices (Table 3). The mean N level at Haa (0.13%) was highly significant compared to those at Thimphu (0.10%) and Paro (0.08%). Significantly higher levels of N were detected in the surface soil and the differences were much greater under inorganic fertilizer practices.

There were no significant differences in the available P between districts and fertilizer practices. The available P was the highest in Thimphu under inorganic practices in the 0–20 cm soil layer and the lowest in Paro from mixed practice in the 21–40 cm soil layer (Table 3).

The trend of K concentration in the soil samples in relation to fertilizer practices was similar to that for the available P, with the highest concentration recorded at Thimphu under inorganic practices in the 0–20 cm soil layer and the lowest was at Haa under organic practices in the 21–40 cm soil layer (Table 3). There were marginal differences observed between inorganic and the organic and mixed practices with a *P*-value of 0.053 which showed that the level of K from inorganic practices was higher than under the other two fertilizer practices.

The soil organic carbon (OC) varied among the fertilizer practices and there were significant differences among districts (Table 3). Orchards at Thimphu and Haa showed highly significant levels of OC compared with those at Paro. In general, there was a moderate level of OC in all orchards except in Paro in the 21–40 cm layer which was low (Table 3).

No significant difference was observed between districts and fertilizer practices within a district for exchangeable Ca. The highest Ca level was from the organic orchards in the 0–20 cm soil layer at Thimphu and the lowest level was also from organic orchards in the 21–40 cm soil depth at Haa (Table 3).

The highest Mg level was in the organic orchards at Thimphu in the 0–20 cm soil layer and the lowest was also from organic orchards at Paro in the 21–40 cm layer (Table 3). There were significant differences observed between fertilizer practices within districts for exchangeable Mg.

The highest CEC values were recorded from mixed fertilizer practices in the 0–20 cm soil layer at Thimphu and the lowest were at Haa from organic practices in the 21–40 cm soil layer (Table 3). The CEC was highly significantly different among districts with the highest from Thimphu (144.6 mmol kg^{-1}) followed by Paro (113.4 mmol kg^{-1}) and Haa (87.8 mmol kg^{-1}).

DISCUSSION

The three common fertilizer practices had no significant effect on the soil nutrient status. There were few significant differences in the nutrient status found among districts and between fertilizer practices except with respect to N, OC and CEC for districts, and soil pH, available K and exchangeable Mg for fertilizer practices which were significant. Highly significant differences between the nutrient levels in the surface soil and subsoil were also observed (Table 2) with the exception of pH that was found to have similar values at the two depths.

The fact that the pH level in the soils was the same and at an optimum level at both soil depths sampled could be explained by the low impact of the land use practices carried out in Bhutanese apple orchards; the soils are still rich and have not been overexploited by the current farming practices. The lower nutrient levels in the subsoil layer compared with those of the surface layer could have been due to the abundance of active apple feeder roots in the 21–40 cm soil layer or the roots of orchard grasses at same layer might have taken up the available nutrient.

The organic fertilizer has had a positive effect on soil as indicated by its corresponding higher pH level. The continuous application of chemical fertilizer in apple orchards decreases the soil pH due to nitrification of the ammonium fertilizers or urea which results in increasing amounts of H^+ ions in the soil (Ruth and Goh, 1992). Saha *et al*. (2010) reported that a higher pH value was recorded from the use of farmyard manure compared to a control. The OM in the soil increases the buffering capacity of that soil; hence, the soil pH is more or less stable. Despites differences, the pH values of the studied soils were mostly within the acceptable range for apple production as suggested by Kanwar (1987).

The level of N was low when compared to criteria suggested in the interpretation of soil analytical data. This showed that there may be either high nutrient competition among the orchard grasses or leaching of N during the rainy season (June–September). In addition, the N fertilizers were not adequate which has a greater impact on the soil N level (Wrona and Sadowski, 2004). There was also a close relationship between the amount of N and the organic carbon in the soil in the current study (Table 3). This result was similar to the findings of Jindaluang *et al*. (2009).

In general, the available P level was rated moderate to high when compared to the standard (Soil Survey Unit, 2010). The higher amount of available P under inorganic fertilizer practices may have been due to the blanket application of P in fertilizer on an annual basis, which in turn may have accumulated in the soil (Table 1). Furthermore, the added P might not have all been taken up by the plants due to the low requirement for P by apple trees (Sadhu, 1988). The decreasing amount of available P with increasing soil depth indicated that the substantial amount of applied P had accumulated in the top soil layer which may have been due to its slow mobility within the soil layer, high competition for P nutrients among orchard grasses at lower soil depths and low fixing capacity within the soil layer (Wojcik and Wojcik, 2007).

The study revealed moderate levels of available K from the inorganic practices. The surface soil (0–20 cm) had a higher amount compared to the subsoil (21–40 cm). The sampled soil showed slow mobility of K and it was restricted within the surface soil. Basso *et al*. (1990) reported that higher available K in the soil was due to the injudicious application almost on an annual basis nutrient containing K. The K contained in inorganic fertilizer that was applied might have contributed sufficient K to the soil.

The level of soil organic carbon (OC) varied among the fertilizer practices (Table 3). However, the results revealed moderate to high levels of OC in the 0-20 cm soil layer and moderate to low levels in the 21–40 cm soil layer when compared to the standard (Soil Survey Unit, 2010). This observation showed that the soil from the studied area contains good amounts of organic matter in the surface layer which may be due to the continuous application of organic manure and the subsequent decay of plant residues such as roots and above ground biomass (Jindaluang *et al.,* 2009; Saha *et al.,* 2010).

According to the information provided by the growers, no liming practices were carried out in the orchards in the study. However, the concentration of exchangeable cations showed levels that were low in Mg and high in Ca among the fertilizer application practices when compared to the nutrient standard (Soil Survey Unit, 2010). This could have been due to the nature of the parent material where the bedrock is mostly gneiss, schist, quartzite and limestone with intrusions (Norbu *et al*., 2003) or due to interactions among the cations. According to Kanwar (1987), Ca is usually available in large quantities in most soils. The studied soils may contain high Ca deposits.

The CEC varied from low to moderate in the surface soil to low in the subsoil. Titus and Boynton (1953) reported that higher organic matter had a higher level of CEC. The CEC also depends on the amount of clay particles and the type of clay minerals (Lhendup and Duxbury, 2008). The moderate to high level of organic matter and the low clay content might have contributed to CEC variation in the study. In general, the CEC was low among the fertilizer application practices except for the surface soil in the inorganic and mixed practices in Thimphu (Soil Survey Unit, 2010).

CONCLUSION

This study showed wide variability in soil nutrients among locations and even between soil depths, which may be influenced by various environmental and cultural factors including soil nutrient management. The nitrogen level in the soil was low which may result in nutrient imbalances in many orchards. The available P and K seemed to be accumulated in the top soil layer; however, their levels were within the recommended range. The difference in nutrient levels between the surface soil (0–20 cm) and the subsoil (21–40 cm) also indicated that collecting soil samples from two depths was necessary for nutrient content analysis in Bhutanese soils.

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