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Macronutrients (NPK) and other soil properties influenced by long term organic and conventional potato farming in West-Central Bhutan

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Abstract There are reported overuse of chemical fertilizers by some conventional potato farmers in Bhutan. On the other hand, over the years, some farmers have been growing potatoes (*Solanum tuberosum* L.) organically**.** The macronutrients (NPK) and other soil properties influenced by long-term organic and conventional potato farming were investigated in Gasa and Wangdue Phodrang Districts in West-Central Bhutan. The total nitrogen (N)% in organic potato soil (0.38%) was significantly higher than in conventional soil (0.26%) at $p<0.01$. Available phosphorus (P) was significantly higher in conventional potato soil (8.87 mg/kg) than in organic soil (4.87 mg/kg) at $p<0.05$. There was no significant difference in available and exchangeable potassium (K) between organic and conventional soils. The pH of conventionally cultivated soil (4.99) was significantly lower than organic soil (5.57) at $p<0.01$. There was a positive correlation (0.883) between total N% and soil organic matter in conventional soil at $p<0.01$. However, no significant difference was observed in the organic matter% content between these farming systems. Further, the Carbon: Nitrogen (C: N) ratio was significantly lower in organic (9.99) than conventional soil (11.52) at $p<0.01$. The cation exchange capacity (CEC) was significantly higher in organic soil (22.26) than in conventional soils (19.45) at $p<0.05$. The study revealed that organic farming led to higher soil residual N and higher CEC than conventional one. It also showed a lower C:N ratio, whereas conventional farming led to higher P but lower pH than organic farming.

Keywords: Farming system, Long-term farming, Soil analysis, Soil properties, Soil sampling

Introduction

FAO (2016) states that there are 16 essential elements present in the soil that promote plant growth and the survival of soil-dwelling organisms. Macronutrients, which are made up of nine components, are the most critical components for plant growth. Among others, Nitrogen (N), Phosphorus (P), and Potassium (K) are important macronutrients required by plants. Soil health is

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comprised of physical and chemical qualities, organic matter, and biological activity in the soil, and these elements also influence its complexity, soil fertility, and productivity, which are critical for sustained agricultural output (FAO, 2009). Organic soil management fertilizes with natural sources such as compost, whereas conventional soil management utilizes mineral fertilizers as the primary source of crop nutrition (Bajgai *et al.*, 2015). Crop nutrients are mostly obtained from two sources: a) Organic sources are those that result from the breakdown of organic biomass through decomposition b) Inorganic sources are those plant nutrients such as macro and micro-ones and soil amendments provided in an artificially made chemical medium known as fertilizers and supplements. Organic manures such as the farmyard manure (FYM) are naturally renewable resources of soil organic matter that include all the required plant nutrients. It offers numerous advantages that improve soils' physical, chemical, and biological characteristics (Subedi and Ma, 2009). The importance of chemical fertilizers in contemporary agriculture cannot be overstated. In the absence of fertilizers, agricultural output would not have been able to meet the rapidly rising food demand of the world's population (FAO, 1998).

Bhutan, a small and mountainous country on the southeast slope of the Himalayas, has been promoting organic farming as a mainstay farming system since 2006 (Department of Agriculture [DoA], 2006). In Bhutan, the potato is an important cash crop mainly cultivated through conventional farming practices using chemical fertilisers and agrochemicals (Lhamo, 2019). However, the conventional potato farmers also use some FYM and other organic amendments along with chemical fertilizers. There was a total area of 4,187 hectares (ha) with a total production of 43,560 metric tonnes (mt) in 2019 under potato farming in the country (Ministry of Agriculture and Forests (MoAF), 2020). About 0.5% of the total potato area is certified organic in Gasa District, corresponding to 20.34 ha (Agriculture Research & Development Centre (ARDC)-Yusipang, 2019). The certified organic potato farmers adhere to Bhutan’s national organic standards and only apply organic fertilizers and amendments such as the FYM and bio-pesticides for crop production.

Bhutan's Himalayan soils are classified as *ferralsols* which are associated with low fertility, poor P availability, soil acidity, and macro and micronutrient deficits (Tashi and Wangchuk, 2016). Conventional agrochemicals such as fertilizers and insecticides are used in minimal quantities in the country and mostly used in key cereals and cash crops, according to (ICIMOD, 2018).

Potato demands a considerable quantity of nutrients while being a high producing, short-duration crop compared to cereals with its shallow root structure. It grows best in sandy-textured, well-drained soils. Since nitrate is prone to leaching losses, these soil types typically make water and N management problematic (Mikkelsen, 2006). Local authorities and agriculture officials in Gangtey and Phobjikha *Gewogs* (a group of villages in Bhutan) under Wangdue Phodrang District are worried about the rising use of chemical fertilizers in potato farming. It appears that farmers in these *Gewogs* are contending to use more chemical fertilizers each year for potato cultivation (Lhamo, 2019). The overuse and inappropriate application of manure and fertilizers in the field have generated public concern over surface and groundwater contamination and gaseous N emissions that harm the environment. Eutrophication is caused by excessive bacteria, an algae bloom in surface waters as a result of excess nutrients, most often of N and P (Subedi and Ma, 2009). Soil fertility is lost, and soils are degraded due to poor farming practices (Kshash and Oda, 2021). As a result, manures and fertilizers must be handled with caution in order to maximize earnings, improve crop quality, conserve energy, and safeguard the environment (Schröder *et al.*, 2000). The substantial rise in atmospheric N_2O is attributable to human changes to the global N cycle, with agricultural soils and N fertilizer accounting for 24% of yearly emissions (Bouwman, 1996, Mosier, 2001). Soil properties such as pH, organic carbon, and CEC impact crop nutrient availability, growth, nutrient use efficiency, and, ultimately, crop productivity (Subedi and Ma, 2009, Westerman *et al.*, 1999).

Potato is one of the cash crops in Bhutan, where farmers use relatively high quantities of agrochemicals (Roder *et al.*, 2008). Consequently, there lies a necessity to examine the effects of long-term conventional and organic potato farming on the physicochemical properties of soil in West-Central Bhutan. However, except for the assessment on organic vis-à-vis conventional rice farming in Bhutan (Tashi and Wangchuk, 2016), no other similar studies have been carried out in the country, especially for important income-generating crops such as potato. Similar studies on the impact of organic and conventional farming on soil properties were implemented by (Adamtey *et al.*, 2016, Bajgai, *et al.*, 2015, Mendoza, 2004, Tashi and Wangchuk, 2016).

The important objective was to determine the long-term effects of organic and conventional potato farming on soil properties in West-Central Bhutan, which included comparing soil nutrient status (NPK) and other soil properties. Soil sampling and analysis can give critical information on the initial point and residual nutrients for crop growth circumstances (Mikkelsen, 2006, Schröder *et al.*, 2000).

Materials and methods

Study area

Gasa and Wangdue Phodrang Districts, both potato-producing and neighbouring districts with similar agro-ecological characteristics in West-Central Bhutan, were selected for the study (Figure 1). Further, Gasa District is the first completely organic district since 2004 (Wangmo and Iwai, 2018). Wangdue Phodrang District is the largest producer of conventional potatoes in West-Central Bhutan (Department of Agriculture (DoA), 2017). Gasa's mean annual temperature is 10°C. It has a total potato area of 30.08 ha and produces 185.24 mt per year (MoAF, 2020). Goenkhatoed *Gewog* (a group of villages in Bhutan), situated at 27°50′N 89°38′E was chosen as a research site for organic potato's soil sampling within the district. The altitude of the *Gewog* extends from 2,100 to 2,800 metres above mean sea level (m.a.s.l). Annual rainfall in the *Gewog* is about 2,241 millimetres (mm) (NSB, 2011a). *Ferralsols* make up Bhutan's Himalayan soils (Tashi and Wangchuk, 2016); this also makes up the soil type in the study area. According to the National Soil Service Centre (NSSC), Thimphu, in 2020, the *Gewog* has loamy and silty clay loam soil texture.

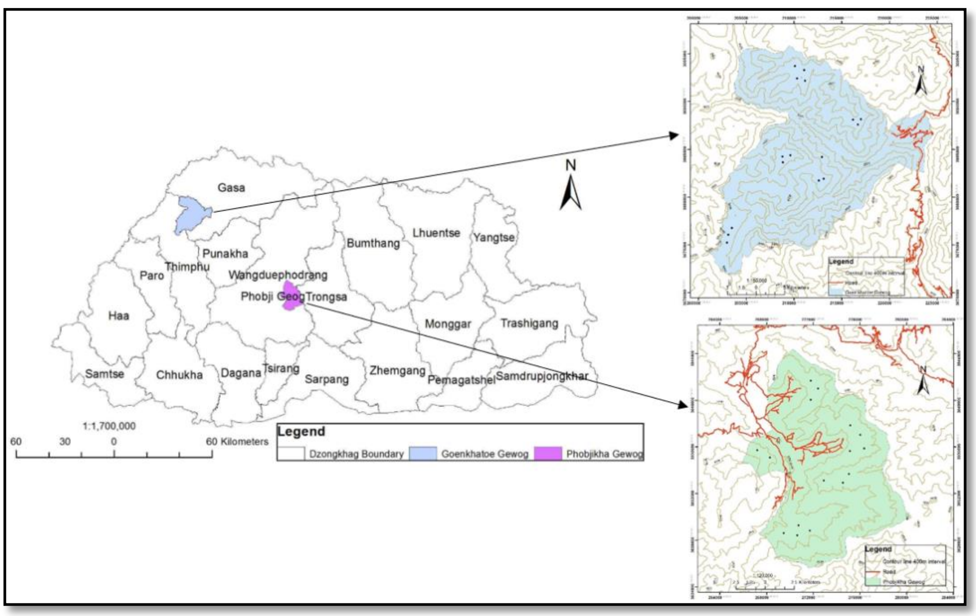

Figure 1. Soil sampling in study areas in Gasa and Wangdue Phodrang Districts, Black dots on the right are probable soil sampling sites (Source the NSSC, Bhutan, 2020)

The average annual temperature in Wangdue Phodrang District is 21 ℃. It has 882.62 ha under potato cultivation, with 15,569.87 mt per year (MoAF, 2020). Phobjikha *Gewog,* located at 27°30′N 90°10′E was chosen as a research site for conventional potato’s soil evaluation. Phobjikha *Gewog* is situated between 2,300 and 4,000 m.a.s.l. It receives 1,099 mm of rain per year (NSB, 2011b). According to the NSSC in 2020, the soil textures in Phobjikha *Gewog* are similar to Goenkhatoed *Gewog*, consisting of loam and silty clay loam. Both research sites are situated in Bhutan's temperate zone above 1,800 m.a.s.l (Feuerbacher *et al.*, 2018).

Sampling procedure

The Goenkhatoed *Gewog*, one of four *Gewogs* in Gasa District, was purposively chosen for the study because it has an organic farmers' group producing certified organic potatoes since 2016 (Department of Agricultural Marketing and Cooperatives [DAMC] & DAS Gasa, 2016). On the other hand, Phobjikha *Gewog*, one of 15 *Gewogs* in Wangdue Phodrang District, was chosen for conventional potato’s soil study. For years, the farmers in the *Gewog* have grown conventional potatoes. Potato farming is their main source of income (Dorji, 2019).

A total of 30 soil samplings were taken from the study sites through a systematic sampling technique. Systematic sampling requires some level of randomness by selecting a random point in the list, and then every n^{th} member is selected until the required number is obtained (Kothari, 2004). In this study, every 3^{rd} farmer was selected until 15 samples were obtained in each farming system. In Goenkhatoed *Gewog* under the Gasa District, the soil samplings were collected from 15 farms, out of 43 organic potato farms, spread across ten villages. In Phobjikha *Gewog* under Wangdue Podrang District, the soil samplings were collected from 15 farms out of 50 conventional potato farms, spread across 11 villages. The soil samples were collected in August-September 2020.

Data collection

Soil samplings were carried out in the study areas according to the standard protocol outlined in the National Soil Service Centre (NSSC) Thimphu, Bhutan field crops soil sampling leaflet (NSSC, 2008). The field was divided into 8 to 10 parts at random to represent the area. Grass and other plant debris on the soil surface were scraped away. A soil sample was taken to a depth of 20 cm with a soil augur and placed on the tray. A composite sample was formed by taking similar soil samples from 8-10 more points and putting them on the tray. All the samples were thoroughly mixed, and any stones or plant roots in the tray were removed. Air-dried composite soil samples were sieved with a 2-mm sieve. A kilogram of composite soil was placed in the plastic bag and appropriately labelled. The soil sample was accompanied by a completed soil analysis request form (soil information sheet). The soil sample was then packed and sent to the NSSC's Soil and Plant Analytical Laboratory (SPAL) for laboratory analysis. Soil samples were taken in the field after the potato crop was harvested (Figure 2). Data on the type and quantity of different fertilizers applied by the potato growers and their socio-demographic characteristics were obtained using a semi-structured questionnaire through face-to-face interviews. It was gathered to understand their farming approach and enrich the discussion holistically.

Figure 2. Soil samplings pictures in Bhutan in 2020

Data analysis

Laboratory analysis of soil

The Soil and Plant Analytical Laboratory (SPAL) at the NSSC, Bhutan, analysed the physicochemical properties of soils. The SPAL is a member of the Southeast Asian Laboratory (SEAL) and is affiliated with the Netherlands University. Other studies have also analysed their soils at the SPAL (Bajgai and Sangchyoswat, 2018, Tashi and Wangchuk, 2016). The total N% was analysed using the Micro-Kjeldahl method. Available P and K were analysed using the Bray method and calcium chloride extraction, respectively. Total carbon was determined using the Walkley-Black method. 1 M ammonium acetate extraction at pH 7 was used to determine exchangeable K and CEC. Using a PHM 83 automatic pH meter, soil pH was determined in distilled water-soil suspension (1:2.5). The hand method is determined the texture of the soil.

Statistical analysis of soil properties

The Independent Sample t-test was used to compare the mean differences of different soil characteristics. The criteria of normal distribution and variance homogeneity were confirmed prior to statistical analysis. All tests were run at a

5% level of significance (Best and Kahn, 1998, Kothari, 2004). The Pearson correlations were used to determine correlations between the soil properties (Tashi and Wangchuk, 2016). The SPSS was used for the data analysis.

Results

Socio-demographic characteristics revealed that the mean age of organic potato farmers was 47 years, whereas it was 40 years for conventional farmers. More female farmers (80%) took up organic potato farming, whereas more male farmers (67%) did conventional potato farming. Educational level was slightly better with the conventional farmers, with more farmers attending primary and middle school. The conventional potato farmers had a larger mean family size (6 persons) than organic farmers (4 persons). Conventional farmers also had larger mean family labour (3 persons) than organic farmers (2 persons). Organic potato farmers had a larger mean farm size (0.99 ha) than the conventional farmers (0.89 ha). Organic farmers had a larger average experience in farming (28 years) than conventional farmers (22 years). Farmers' training was attended more by organic farmers (1.5 times/year) than the conventional farmers (1 time/year) (Table 1).

Table 1. Socio-demographic profile of the farmers

Variables	Organic farmers				Conventional farmers			
	Mean	**S.D**	**Min**	**Max**	**Mean**	**S.D**	**Min**	**Max**
Age	47.73	15.31	26	71	40.87	8.06	29	56
Sex	-	-	3 M	12 F	-	-	5 F	10 M
Education level	4 (PS), 1 (NF), 10 (I)				5 (PS), 1 (MS), 2 (NF), 7 (I)			
Household size (numbers)	3.47	1.77	1	7	6	2.29	3	10
Family labour (person)	1.67	0.72	1	3	3.13	1.36	2	6
Farm size (ha)	0.99	0.72	0.13	2.82	0.89	0.44	0.40	1.82
Farming experience (years)	28.47	19.32	5	60	22	7.36	10	35
Farmers' training (numbers/year)	1.47	0.92	0	3	1.13	0.83	0	2

M=male, F=Female; PS (Primary school), NF (Non-formal), I (Illiterate), MS (middle school).

Organic potato farmers applied around 41 mt/ha of FYM & other organic amendments in 2019, supplying about 449 kgs/ha of N, 224 kgs/ha of P, and 815 kgs/ha of K. The conventional potato farmers added around 16 mt/ha of FYM & other organic amendments, 0.004 mt/ha of urea (0:46:0), 0.74 mt/ha of Suphala (15:15:15), and 0.23 mt/ha of single super phosphate (SSP) (0:16:0) in 2019. As a result, it supplied around 287 kgs/ha of N, 235 kg/ha of P, and 428 kgs/ha of K (Table 2 and Figure 3).

Table 2. Different types and average quantities of chemical and organic fertilizers applied in the cropping cycle 2019

Farming type in potato	Organic amendments (mt/ha)	Chemical fertilizers (mt/ha)			NPK (Kg/ha)		
	FYM & other organic amendments	Urea (0:46:0)	Suphala (15:15:15)	Single Super Phosphate (0:16:0)	N	P	K
Organic	41.34	-	-	-	449.78	224.89	815.22
Conventional	16.08	0.004	0.74	0.23	287.79	235.28	428.10

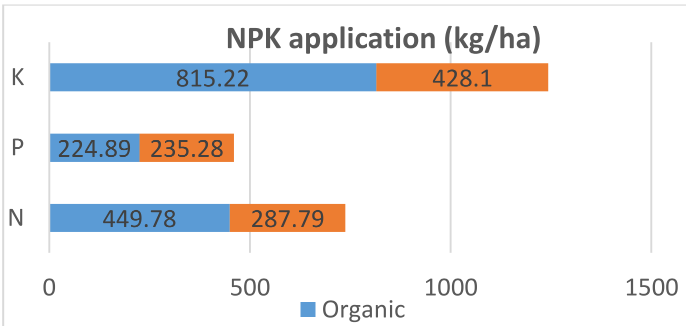

Figure 3. Graphical representation of NPK applied by the potato farmers

Both organic and conventional potato fields had similar soil textures consisting of loam and silty clay loam. The analysis indicated that the soils in the organic field comprised 73.3% loam and 26.7% silty clay loam. In conventional fields, 60% of the soil textures constituted silty clay loam, while the remaining 40% was loam.

The results showed that the pH (H_2O) of conventional soils (4.99) was significantly lower than the organic soils (5.57) at $p<0.01$. The available (Av.) P was significantly higher in the conventional soils (8.87 mg/kg) than the organic soils (4.87 mg/kg) at $p<0.05$. Organic matter (OM) (%) content was not significantly different between organic and conventional soils. Total N% was significantly higher in the organic soils (0.38%) compared to the conventional soils (0.26%) at $p<0.01$. The Carbon: Nitrogen (C: N) ratio was significantly lower in organic soils (9.99) than conventional soils (11.52) at $P<0.01$. There were no significant differences in Av. K between the two farming systems. The mean Av. K for organic and conventional soils were 183.02 and 143.47 mg/kg, respectively. There were also no significant differences in exchangeable (Ex.) K between the two farming systems. The cation exchange capacity (CEC) (me/100g) was significantly higher in the organic soils (22.26) than the conventional soils (19.45) at $P<0.05$ (Table 3).

Table 3. Comparisons of means of different soil properties (independent sample t-test, N=30)

Item[†]	Mean		d.f.	t-test	p-value
	Organic	Conventional			
pH (H_2O)	5.57	4.99	28	4.41	0.000**
Av. P (mg/kg)	4.87	8.87	28	-2.392	0.024*
OM (%)	5.87	5.10	28	1.700	0.100
Total N (%)	0.38	0.26	28	3.848	0.001**
C:N ratio	9.99	11.52	28	-3.304	0.003**
Av. K (mg/kg)	183.02	143.47	28	1.214	0.235
Ex.K (me/100g)	0.84	0.51	28	1.001	0.326
CEC (me/100g)	22.26	19.45	28	2.483	0.019*

N=Number of samples: organic soil (n1) = 15; conventional soil (n2) = 15. *$p<0.05$; **$p<0.01$.

The Pearson correlation between different soil properties under organic potato farming showed that the soil organic matter (SOM) was correlated with C:N ratio and CEC at $P<0.05$. Furthermore, total N% was correlated with CEC at $P<0.05$ (Table 4).

Table 4. Correlations between different soil properties under organic potato farming (Pearson correlation)

Soil property	C:N ratio	CEC
SOM	0.534*	0.517*
Total N%		0.540*

*$p<0.05$

Similarly, the Pearson correlation between different soil properties under conventional potato farming showed that its pH was correlated with the Av. K at $P<0.05$, Ex. K at $P<0.01$. The SOM was correlated with total N% at $P<0.01$ and the CEC at $P<0.05$. Total N% was correlated with the CEC at $P<0.05$ (Table 5).

Table 5. Correlations between different soil properties under conventional potato farming (Pearson correlation)

Soil property	Total N%	Av. K	Ex. K	CEC
pH		0.612*	0.719**	
SOM	0.883**			0.551*
Total N%				0.610*

*$p<0.05$; **$p<0.01$

† Items arranged as per the soil analysis report

Discussion

To understand the farming approach holistically and facilitate meaningful discussions, the study also delved into soil fertility management in the 2019 cropping cycle and the socio-demography characteristics of target farmers. Both the organic and conventional potato farmers were well experienced in their farming practices. The organic farmers possessed a relatively larger farm area than the conventional farmers, whereas the conventional farmers had comparatively more family labour than organic farmers. Technical farmer's training was attended more by the organic farmers than conventional ones. Organic potato farmers applied only organic fertilizers in their fields, comprising of FYM and other organic fertilizers. On the other hand, conventional potato farmers used both chemical fertilizers and some quantities of organic fertilizers. The recommended rates of fertilizer application in Bhutan for potato cultivation depending on location are 59-100 kg N/ha and 26-34 kg P/ha (Roder *et al.*, 2008). Considering an estimated proportion of N available to the potato crop through the application of the FYM was at 30% (BPDP, 2008), both organic and conventional potato farmers applied N more than the recommended rates. The N available to potatoes with organic fertilizer only in organic farming is estimated to be 134 kg/ha, whereas it was 165 kg/ha for conventional farming with the combined chemical and organic fertilizers. This agrees with the report (BPDP, 2008) that many potato farmers in Central and Western Bhutan applied fertilizers (in combinations of chemical and organic fertilizers) more than the N and P recommended rates. The NPK from the FYM and organic fertilizers were computed based on the (Chettri *et al.*, 2003); the authors reported that the FYM produced through a heap-storage method in Bhutan has a dry matter content of around 68% with 1.6% N, 0.8% P, and 2.9% K of dry matter nutrient contents.

The ideal soil pH is >5.5 (water), and below that, it is regarded as highly acidic, which has a higher risk of aluminium toxicity. The key plant nutrients may have limited availability to plants in acidic soils with pH less than 4.8 ($CaCl_2$) or 5.5 (water) (Botta, 2015). The significantly lower pH of conventional potato soil than the organic soils and below the ideal one suggest a highly acidic one. Long-term alterations in soil pH resulted primarily from cation displacement or the addition of acidity sources such as H+ to the soil's exchange sites (Tisdale *et al.*, 1993). Norbu and Floyd (2004) mentioned that the widespread application of urea in Bhutan is likely to intensify the low soil pH issue. Liming to neutralize acidic soils is not a common practice in Bhutan. The prolonged use of chemical fertilizers such as urea could have lowered the pH of the conventional soil, accompanied by poor soil fertility management.

This finding contradicts (Tashi and Wangchuk, 2016), where soil pH was not significantly different in organic and conventional rice fields in Bhutan.

Significantly higher available P in the conventional soil than the organic soil could have been due to the P build-up with a long-term application of chemical P fertilizer in the form of Single Super Phosphate (SSP, 16% of P_2O_5) along with organic fertilizers. Similar results were reported by (Bajgai, *et al.*, 2015, Grewal *et al.*, 1981). On the contrary, (Herencia and Maqueda, 2016, Tashi and Wangchuk, 2016) found that available P in organically managed soils was significantly higher than conventional. Soil sample with <5 mg P/kg and <15 mg P/kg is considered to contain very low and low levels of P, respectively (Roder, *et al.*, 2008). This indicates that the organic potato soil had a very low level (4.87 mg P/kg) while the conventional soil had a low level of P (8.87 mg P/kg). After N, P is often considered the next most crucial nutrient limiting crop yield in Bhutan (Chettri *et al.*, 2003). P is required for energy storage and transmission, early shoot and root development, and legume nodulation functions in plants (Botta, 2015).

The lack of significant differences in organic matter content between the organic and conventional soils could be due to the conventional farmers' practice of applying organic fertilizers besides chemical fertilizers. There was an increase in the soil's organic C pool in field experiments using integrated nutrient management methods (Choudhary *et al.*, 2013). In contrast, in two consecutive years, the soil organic matter (SOM) was consistently and significantly higher in the organic rice farm in Bhutan (Tashi and Wangchuk, 2016).

Interestingly, total N was significantly higher in the organic soils than conventional soils. The N is a critical plant nutrient since it is required to produce proteins and chlorophyll, the preservation of photosynthetic efficiency, the increase of leaf area, and, eventually, the synthesis of dry matter. It concerns one of the essential yield-limiting nutrients on the planet (Muchow, 1998). Similar results of higher N percent availability in organic plots than the conventional plots were reported by (Bajgai, *et al.*, 2015, Das *et al.*, 2017, Tashi and Wangchuk, 2016). The N mineralization rates of a conventional system are estimated to be 100% greater than an organic one; therefore, organic soil management systems are expected to retain more N (Bajgai, *et al.*, 2015, Mallory and Griffin, 2007). Plant nutrients stored in SOM are released into the soil as inorganic forms through decomposition and mineralization (Jarvis *et al.*, 1996). In these systems, N supply is frequently restricted by mineralization and immobilization processes and can be unexpected, resulting in excess or insufficient asynchrony (Mallory and Griffin, 2007, Palmer *et al.*, 2013). Organic potato farmers added the FYM and other organic fertilizers 2.57 times more than the conventional farmers per hectare of the land. The presence of correlation between the SOM with the total N in the conventional soils also supports this view. N applied through urea and other chemical fertilizers in conventional farming are readily absorbed by the plants, remaining are lost as leaching and volatilization losses. The use of readily accessible conventional fertilizers may lead to losses such as denitrification and leaching (Chien *et al.*, 2009, Hirel *et al.*, 2007). The N use efficiency for chemical fertilizers is higher than the organic fertilizers (Adamtey, *et al.*, 2016, Eghball and Power, 1999). Due to its excellent mobility and tendency for loss from the soil-plant system into the environment, N management is a critical problem in most agricultural systems (Musyoka *et al.*, 2017). Further, the N mineralization and thereby its availability to plants is also affected by the soil pH. It was found that the pH of conventional soil was significantly lower than that of organic soil. Mallory and Griffin (2007) reported that the organic N mineralization is known to decrease gradually when pH falls below pH 6.

The significantly higher N content of organic field soils than the conventional ones but with similar carbon content led to a significantly higher C:N ratio in the conventional ones than the organic ones. The C:N ratio indicates the pattern of N mineralization and immobilization (Reddy and DeLaune, 2008). The lower C:N ratio in the organic soils could be due to the addition of large amounts of cow dung manure in FYM. Due to its high N content, cow dung manure has a lower C:N ratio (Adegunloye *et al.*, 2007).

Interestingly, no significant differences in available and exchangeable K were observed between organic and conventional systems. Similar results were obtained by (Herencia and Maqueda, 2016, Tashi and Wangchuk, 2016). K is essential in plants for controlling water and nutrient absorption, blooming and seed development, and tolerance to environmental stressors and disease (Botta, 2015). In research on changing soil fertility management in Bhutan, Norbu and Floyd (2004) reported that the soil parent materials are generally rich in K in the country, as evidenced by mostly moderate to high amounts of exchangeable K.

Higher CEC in organic soils than conventional soils could be due to the application of higher quantities of SOM in the form of organic fertilizers. The CEC and the SOM were correlated in both the farming system soils, suggesting that the higher CEC in the organic soils was due to the application of higher quantities of organic fertilizers. Similar results were obtained by (Bajgai *et al.*, 2015, Schjønning *et al.*, 1994, Sidhu *et al.*, 2007).

Conventional potato farming was found to lower soil pH than organic farming, possibly due to the prolonged use of mineral fertilizers such as urea. Such a situation can affect the availability of various nutrients to the potato crop. Therefore, conventional farmers are recommended to use lime ($CaCO_3$) in their soil to rectify the acidic soil. However, this study could only collect 30 soil samples (15 for each farming system); therefore, it is suggested that other studies with a higher sample size encompassing other physicochemical soil properties could be taken up. Nevertheless, the research could generate empirical data on selected soil properties induced by organic and conventional potato farming in West-Central Bhutan. Such findings will be informative and helpful to policymakers, agriculture officials, academicians, local and global researchers, farmers, and agriculture development.

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References

Adamtey, N., Musyoka, M. W., Zundel, C., Cobo, J. G., Karanja, E., Fiaboe, K. K. M., Muriuki, A., Mucheru-Muna, M., Vanlauwe, B., Berset, E., Messmer, M. M., Gattinger, A., Bhullar, G. S., Cadisch, G., Fliessbach, A., Mader, P., Niggli, U. and Foster, D. (2016). Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya. Agriculture Ecosystems & Environment, 235:61-79.

Adegunloye, D., Adetuyi, F., Akinyosoye, F. and Doyeni, M. (2007). Microbial analysis of compost using cowdung as booster. Pakistan Journal of Nutrition, 6:506-510.

Agriculture Research & Development Centre (ARDC)-Yusipang (2019). Annual report (2018-2019), ARDC-Yusipang, Royal Government of Bhutan. In: D.o. Agriculture (ed), Department of Agriculture, Thimphu, 106:i-x.

Bajgai, Y., Kristiansen, P., Hulugalle, N. and McHenry, M. (2015). Comparison of organic and conventional managements on yields, nutrients and weeds in a corn-cabbage rotation. Renewable Agriculture and Food Systems, 30:132-142.

Bajgai, Y. and Sangchyoswat, C. (2018). Farmers knowledge of soil fertility in West-Central Bhutan. Geoderma Regional, 14:8

Best, J. W. and Kahn, J. V. (1998). Research in education, Boston, Allyn and Bacon.

Botta, C. (2015). Understanding your soil test step by step, Shepparton, pp. i-vi, 1-49.

Bouwman, A. (1996). Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems, 46:53-70.

BPDP (2008). Soil fertility management for sustained potato production in the mountain of Bhutan., 2008, (CIP/CFC/BPDP Thimphu),

Chettri, G. B., Ghimiray, M. and Floyd, C. N. (2003). Effects of farmyard manure, fertilizers and green manuring in rice-wheat systems in Bhutan: Results from a long-term experiment. Experimental Agriculture, 39:129-144.

Chien, S., Prochnow, L. and Cantarella, A. H. (2009). Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. Advances in agronomy, 102:267-322.

Choudhary, A. K., Thakur, S. K. and Suri, V. K. (2013). Technology Transfer Model on Integrated Nutrient Management Technology for Sustainable Crop Production in High-Value Cash Crops and Vegetables in Northwestern Himalayas. Communications in Soil Science and Plant Analysis, 44:1684-1699.

Das, A., Patel, D. P., Kumar, M., Ramkrushna, G. I., Mukherjee, A., Layek, J., Ngachan, S. V. and Buragohain, J. (2017). Impact of seven years of organic farming on soil and produce quality and crop yields in eastern Himalayas, India. Agriculture Ecosystems & Environment, 236:142-153.

Department of Agricultural Marketing and Cooperatives [DAMC] & DAS Gasa (2016). Gasa Dzongkhag leading the way in organic crop production (MoAF, Thimphu).

Department of Agriculture (DoA) (2017). Agriculture Statistics 2016. In: D.o. Agriculture (ed), Department of Agriculture, Ministry of Agriculture & Forests (MoAF) Thimphu, Bhutan, 81.

Department of Agriculture [DoA] (2006). National Framework for Organic Farming in Bhutan In: D.o. Agriculture (ed), Department of Agriculture, Royal Government of Bhutan (RGoB), Thimphu, Bhutan, 44.

Dorji, C. (2019). Potato farmers of Gangteng and Phobji use more fertilisers for better yield. 2019, (Bhutan Broadcasting Service (BBS).

Eghball, B. and Power, J. F. (1999). Composted and noncomposted manure application to conventional and no-tillage systems: Corn yield and nitrogen uptake. Agronomy journal, 91:819-825.

FAO (1998). Guide to efficient plant nutrition management. Land Water Development Division. FAO, Rome, Italy,

FAO (2009). Sustainable Potato Production - Guidelines For Developing Countries, Food and Agriculture Organization of the United Nations pp. 91.

FAO (2016). Climate change and food security: risks and responses. Food and Agriculture Organization of the United Nations (FAO) Report, 110.

Feuerbacher, A., Luckmann, J., Boysen, O., Zikeli, S. and Grethe, H. (2018). Is Bhutan destined for 100% organic? Assessing the economy-wide effects of a large-scale conversion policy. PloS one, 13:24.

Grewal, J., Sharma, R. C. and Sud, K. (1981). Effect of continuous application of PK-fertilizers and farmyard manure on potato yield and some soil properties. Journal of the Indian Society of Soil Science, 29:129-131.

Herencia, J. F. and Maqueda, C. (2016). Effects of time and dose of organic fertilizers on soil fertility, nutrient content and yield of vegetables. Journal of Agricultural Science, 154:1343-1361.

Hirel, B., Le Gouis, J., Ney, B. and Gallais, A. (2007). The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and quantitative genetics within integrated approaches. Journal of Experimental Botany, 58:2369-2387.

ICIMOD (2018). Organic Agriculture Development Strategies: Roadmap for 12th Five Year Plan and Beyond. 2018, (Integrated Centre for Mountain Development (ICIMOD), 34.

Jarvis, S. C., Stockdale, E. A., Shepherd, M. A. and Powlson, D. S. (1996). Nitrogen mineralization in temperate agricultural soils: processes and measurement. Advances in agronomy, 57:187-235.

Kothari, C. R. (2004). Research methodology: Methods and techniques, New Delhi, India, New Age International Publishers, pp. i-xvi, 1-401.

Kshash, B. and Oda, H. (2021). Awareness and use of soil conservation practices among Iraqi wheat farmers. International Journal of Agricultural Technology, 17:1373-1382.

Lhamo, P. (2019). In Phobji and Gangtey, farmers compete to use more fertilisers.

Mallory, E. and Griffin, T. (2007). Impacts of soil amendment history on nitrogen availability from manure and fertilizer. Soil Science Society of America Journal, 71:964-973.

Mendoza, T. C. (2004). Evaluating the benefits of organic farming in rice agroecosystems in the Philippines. Journal of Sustainable Agriculture, 24:93-115.

Mikkelsen, R. (2006). Best management practices for profitable fertilization of potatoes. Magnesium (Mg), 25:40.

Ministry of Agriculture and Forests (MoAF) (2020). Agriculture Statistics 2019. In: D.o. Agriculture (ed), 2020, (Renewable Natural Resources Ststistics Division (RSD), Thimphu, Bhutan), I-VII, 1-123.

MoAF (2020). Agriculture Statistics 2019. In: D. Services (ed), 2020, (Renewable Natural Resources Statistics Division (RSD), Royal Government of Bhutan, Thimphu), I-VII, 1-123.

Mosier, A. R. (2001). Exchange of gaseous nitrogen compounds between agricultural systems and the atmosphere. Plant and Soil, 228:17-27.

Muchow, R. (1998). Nitrogen utilization efficiency in maize and grain sorghum. Field Crops Research, 56:209-216.

Musyoka, M. W., Adamtey, N., Muriuki, A. W. and Cadisch, G. (2017). Effect of organic and conventional farming systems on nitrogen use efficiency of potato, maize and vegetables in the Central highlands of Kenya. European Journal of Agronomy, 86:24-36.

Norbu, C. and Floyd, C. (2004). Changing soil fertility management in Bhutan: Effects on practices, nutrient status and sustainability.

NSB (2011a). Annual Dzongkhag Statistics 2011 (Dzongkhag Administration Gasa). In: N.S. Bureau (ed), 2011a, (National Statistics Bureau, Bhutan), i-iii, 1-48.

NSB (2011b). Annual Dzongkhag Statistics 2011 (Dzongkhag Administration Wangdue Phodrang). 2011b, (National Statistics Bureau Bhutan), i-iv, 1-51.

NSSC (2008). Field Crops soil sampling (Leaflet No.2). 2008, (National Soil Service Centre (NSSC), Dept. of Agriculture.

Palmer, M. W., Cooper, J., Tetard-Jones, C., Srednicka-Tober, D., Baranski, M., Eyre, M., Shotton, P. N., Volakakis, N., Cakmak, I., Ozturk, L., Leifert, C., Wilcockson, S. J. and Bilsborrow, P. E. (2013). The influence of organic and conventional fertilisation and crop protection practices, preceding crop, harvest year and weather conditions on yield and quality of potato (Solanum tuberosum) in a long-term management trial. European Journal of Agronomy, 49:83-92.

Reddy, K. R. and DeLaune, R. D. (2008). Biogeochemistry of Wetlands: Science and Applications, CRC Press, pp.

Roder, W., Nidup, K. and Chettri, G. B. (2008). The Potato in Bhutan, Thimphu, Bhutan Potato Development Progam, pp. i-viii, 185.

Schjønning, P., Christensen, B. and Carstensen, B. (1994). Physical and chemical properties of a sandy loam receiving animal manure, mineral fertilizer or no fertilizer for 90 years. European Journal of Soil Science, 45:257-268.

Schröder, J., Neeteson, J., Oenema, O. and Struik, P. (2000). Does the crop or the soil indicate how to save nitrogen in maize production?: Reviewing the state of the art. Field Crops Research, 66:151-164.

Sidhu, A. S., Thind, S. S., Sekhon, N. K. and Hira, G. S. (2007). Effect of farmyard manure and p application to potato on available p and crop yield of potato (Solanum tuberosum)-sunflower (Helianthus annuus) sequence. Journal of Sustainable Agriculture, 31:5-15.

Subedi, K. and Ma, B. (2009). Corn crop production: growth, fertilization and yield. Agriculture issues and policies.

Tashi, S. and Wangchuk, K. (2016). Organic vs. conventional rice production: comparative assessment under farmers' condition in Bhutan. Organic Agriculture, 6:255-265.

Tisdale, S., Nelson, W., Beaton, J. and Havlin, J. (1993). Soil fertility and fertilizers., 5th edn, Macmillan, New York.

Wangmo, S. and Iwai, C. B. (2018). Performance of Organic Agriculture (OA) based on Emergent Properties of Agriculture System in Gasa, Bhutan. Khon Kaen Agriculture Journal, 1985:1202-1210.

Westerman, R., Raun, W. and Johnson, G. (1999). Nutrient and water use efficiency. Handbook of soil science. CRC Pres, Boca Raton, FL:175-189.

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