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Evaluation of trends in integration of organic farming system into potato farming : Soil fertility and productivity

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Abstract

Application of chemical fertilizers is the general fertilization practice in the potato (*Solanum tuberosum* L.) farming system. Present trend is application of animal manure along with reduced rates of chemical fertilizers in potato farming. Precise impacts of incorporation of organic farming system into conventional farming system was evaluated by means of potato productivity and soil fertility using major potato growing fields in Sri Lanka. Three clusters were selected on the basis of different fertilizations, and physical and chemical properties of soils were analyzed. Productivity and production costs of potato were also assessed in all clusters from 2003 to 2005. Major nutrient levels were higher than the required amounts for potatoes in all clusters in both manure amended systems (MASs) and manure unamended systems (MUSs), but there was no significant difference in major nutrient levels between MASs and MUSs. However, the tuber yield was not affected by incorporation of organic farming system and showed a strong positive linear correlation with sand : clay ratio of soil. Animal manure amended systems reduced the potato production costs by 3.0-7.2% without affecting the tuber yield, and thereby increasing the benefit to cost ratio.

Key words: Land classes, chemical fertilizer, organic farming, potato yield

Introduction

The potato (*Solanum tuberosum L.*) is one of the most popular tuber crops in Sri Lanka, and soil nutrient status and soil texture are recognized as major determining factors in potato production. Nutrient management literally is a key factor for achieving sustainable agriculture (Oenema *et al.,* 2006). In particular there should be a critical nutrient balance in the

potato cultivation, since it is a short term annual crop and the crop has a high demand for soil nutrients (Roy *et al.,* 2001; Bierman, *et al.,* 2005). However, nutrients in the fields should be properly managed to avoid inputs of excess amounts of fertilizers. At present commercial scale potato production in the world mainly based on chemical fertilizers, and pure organic farming systems are operated only at a small scale, but integrated farming systems of organic and inorganic are very often practiced in potato production. Since soil fertility levels are critical factors and the potato is a short term annual crop, pure organic farming systems are still not popular. Hence, in this study soil fertility levels and potato productivity of integrated farming systems were evaluated and economical benefits were also assessed. And the study was conducted in major potato growing fields in Sri Lanka where potatoes are grown as the major vegetable crop.

In Sri Lanka, generally, Nitrogen (N), potassium (K) and phosphorus (P) fertilizers are applied to potato crop as chemical fertilizers. Application of chemical fertilizers as basal application during land preparation, and as side dressing at earthing up stage is the common fertilizer input practice in potato cultivation. Because of present trend in organic foods and the escalating price of chemical fertilizer, most farmers have adopted the practice of incorporating low cost animal manure (organic fertilizer) in a certain proportion to the chemical fertilizer in order to reduce high cost fertilizer inputs. However, effects of application of organic manures on potato cultivation have been studied by several researchers, and evaluated the soil fertility levels and shown a positive impact on the soil fertility. Poultry manure is widely used as an alternative nutrient source of N, P, K for crops (Mitchell and Tu, 2006) and is approximately equivalent to a 3-3-2 grade ($N\text{-}P_2O_5\text{–}K_2O$) fertilizer (Stephension *et al.,* 1990; Mitchell and Donald, 1995). In general animal manure amended soils comprise higher levels of soil organic matter than unamended soils (Wander *et al.,* 1994; Grandy, *et al.,* 2002). Soil organic matter plays an important role in maintaining productivity of soils (Vanlauwe *et al.,* 2001, Zhang and He, 2004; Ohno *et al.,* 2005) by increasing microbial activity and improving related physical, chemical and biological properties (Ros, 2006) and soil structure by binding soil particles. Therefore, adding organic fertilizer is directly contributing to the crop production (He and Lin, 1992). Studies have shown that cropping systems, that utilize animal and green manures have a positive impact on crop yields while reducing application of chemical fertilizers (Tisdale *et al.,* 1993; Karlen, *et al.,* 1994) and may increase soil P availability (Ohno, *et al.,* 2005).

Organic farming without use of synthetic chemicals is becoming increasingly popular in Sri Lanka. Since the potato crop is a fast growing short-term crop, which needs large quantities of nutrients, potato farmers

use combinations of chemical fertilizer and animal manure for cropping. With rising interest in ecofriendly farming systems concerning less chemical fertilizer inputs to the soil environment through fertilizer management, the study was undertaken to evaluate soil nutrient levels of potato growing fields, fertilized with chemical fertilizer alone, and combinations of chemical and animal manure as an organic fertilizer.

Materials and Methods

Potato growing areas and cultivation pattern in Sri Lanka

Major potato growing areas in Sri Lanka are in central hilly lands, where the predominant soil type is Red-Yellow Podzolic soils (great soil group), and they are the model soils of the wet zone of Sri Lanka (Panabokke,1996). Potato farmers in the study area use two major growing seasons (*yala and maha*), two land classes (uplands and lowlands), and their own cropping patterns based on the traditional practices. Lowland cultivation is totally dependent on irrigated water, while upland cultivation is mostly dependent on rainwater.

Site selection

This study was totally based on the real ground conditions, and the experimental sites were selected from Nuwara Eliya and Badulla districts in the central hilly lands, where potatoes are extensively cultivated in Sri Lanka. The area received an average annual rainfall ranging from 1400 to 1700 mm (5 year average from 2001 to 2005) and falls into the up-country wet zone and the up-country intermediate zone of major climatic zones of Sri Lanka. The study area was characterized by practicing over 25 years of potato cultivation, where major cropping systems observed were rotations of paddy-potato-vegetable (beans, cabbage, tomatoes) in lowlands and potato-vegetable-fallow in uplands. Three major growing areas (clusters 1, 2 and 3), comprising both uplands and lowlands were selected (Figure 1); subsequently 16 fields in each cluster were selected considering types of fertilizer application over ten years. These three clusters received different formulation of animal manure and chemical fertilizers, chemical to manure ratio in cluster 1 was 3:2 (cattle manure as organic fertilizer), in cluster 2, 3:1 (poultry manure as organic fertilizer) and in cluster 3, 3:2 (poultry manure as organic fertilizer). The study was undertaken in *yala* season i.e. May to September and *maha* season i.e. November to February, during the period from 2003 to 2005 with 48 potato-growing fields. In uplands, potatoes are grown as a rainfed crop, while in lowlands potato fields are irrigated by stream and well waters using pumps and small irrigation systems. In the study area, several potato varieties were grown, but Granola was the most popular variety, which

had been grown in most of fields for a longer period. Therefore, the fields used for this study were mainly Granola grown fields. All selected fields were small-scale household farms and cultivated area ranged from 0.04 to 0.2 ha. Four replicate blocks were used for each cluster in each season.

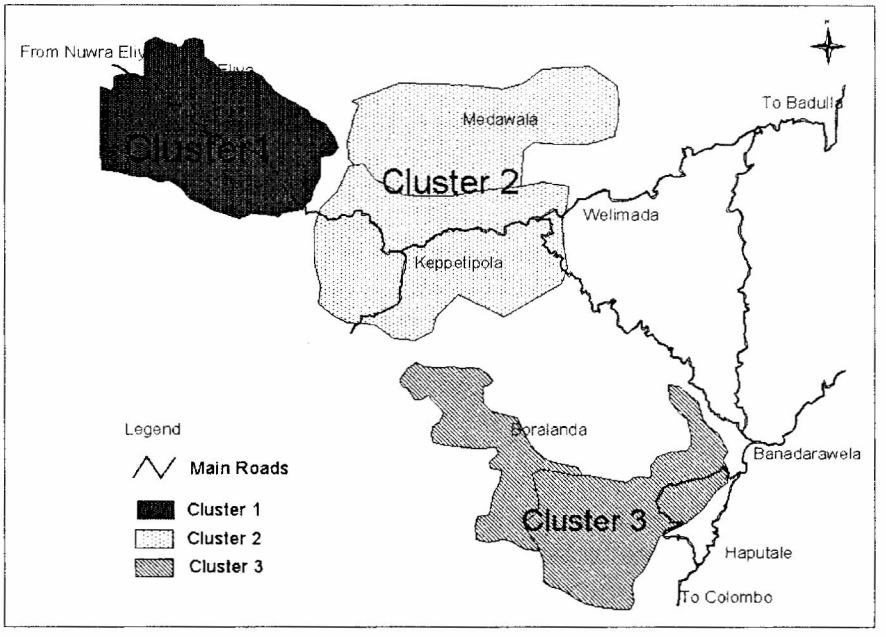


Figure 1 .Map of study area showing 3 clusters

Field data on land form, cropping systems, time of planting, fertilization practices, types of fertilizers used, harvesting and tuber yield were recorded, and soil samples were collected one week after the harvest.

Fertilizer application practices

The replicated fields comprised manure amended Systems (MASs) and manure unamended systems (MUSs) in uplands and lowlands. Unamended fields received only normal chemical fertilization intensities as a mixture of urea, triple phosphate and muriate of potash and the range of 2000-2500 kg ha^{-1}, while manure amended fields received animal manure, in the form of cattle manure or poultry manure (well-rotten) and reduced rates of chemical fertilizers at the weight ratio of 3:2 or 3:1 (chemical fertilizer : manure). In each manure treatment, the entire animal manure was applied along with 1000–1250 kg ha^{-1} of chemical fertilizers as basal application prior to planting, and only chemical fertilizers at the earthing up stage as normal fertilization practice.

The recommended fertilizers (The Agriculture Department, Sri Lanka) in Sri Lanka are formulation and rates of N-P-K fertilizers 1000 kg ha^{-1} of ammonium sulphate, 250 kg ha^{-1} of triple superphosphate and 150 kg ha^{-1} of muriate of potash for Nuwara Eliya district, and 500 kg ha^{-1} of ammonium sulphate, 250 kg ha^{-1} of triple superphosphate and 150 kg ha^{-1} of muriate of potash for Badulla district. The recommendations are location specific rather than situation specific, since quantification for an individual situation is not feasible (Kularatne,2003)

Soil Sampling and analysis

Soil properties were determined from samples collected from potato fields. Three soil cores were taken randomly at 0–20 cm depth from each experimental site covering uplands and lowlands (paddy fields) using 5 cm soil auger, and the cores were bulked to make one sample per field. Then all samples were sieved through 2.0 mm sieve separately. Sub-samples of each soil were air dried and analysed for chemical properties.

Total soil N was determined by Kjeldahl method. Extractable P, K. Mg and Ca were determined using an Atomic Absorption Spectrophotometer (Model,GBC 933AA) after wet digestion of soil samples. Organic carbon was measured using modified Walkely and Black method (Allison, 1965; Walkely and Black, 1934) and C:N ratio was also determined in potato grown soils. Soil pH was measured with a glass electrode using an aqueous extract (1:2.5, soil : water, w:v).

Physical properties of soils
Soil textural classes were determined using graphic guide for textural classification of less than 2.0 mm portion. (Source: USDA – Soil Conservation Service) and Soil colour was described using the Munsel Colour Chart.

Statistical analysis

All data were analyzed at an alpha level of 0.05 in a completely randomized design model using Windows Microsoft Excel. To determine the effects of fertilizer type and rates, and significance of other parameters on yield, Two-way ANOVA and Tukey's studentized range test were used. A replicate represented the average of two seasons. Correlation coefficients and linear regression were also calculated.

Results

This study revealed that there were no marked differences in major nutrient levels in soils between MAS and MUS. Both uplands and lowlands of all three clusters showed excess amounts of soil nutrients due to continuous application of fertilizers in these fields resulting accumulation of high levels of nutrients. (Table 1)

Table 1: Major soil nutrients in manure amended systems (MAS) and Manure unamended systems (MUS). Values are means of four replicates ± S.e. Figures within each column and each land class of each cluster followed by "ns" are not significantly different. $P<0.05$, n=4.

Cluster	Land class	Manure amendment	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})
Cluster 1	Uplands	40%	1781±264	1052±31 ns	174±10	3662±91	919±12 ns
		0 %	908±21	1028±20 ns	213±09	3144±48	904±08 ns
	Lowlands	40%	2409±95 ns	982±11 ns	202±14 ns	2186±96 ns	325±07
		0 %	2166±202 ns	973±16 ns	233±32 ns	2381±88 ns	439±22
Cluster 2	Uplands	25%	1386±130 ns	251±45 ns	160±06 ns	963±12 ns	154±19 ns
		0 %	848±187 ns	195±08 ns	220±43 ns	430±285 ns	145±59 ns
	Lowlands	25%	1266±73 ns	322±31 ns	95±11	1004±06	380±54 ns
		0 %	1281±91 ns	264±15 ns	168±06	279±77	451±78 ns
Cluster 3	Uplands	40%	1479±153 ns	678±60 ns	168±34 ns	874±26 ns	334±30 ns
		0 %	1325±223 ns	637±77 ns	198±08 ns	885±20 ns	332±11 ns
	Lowlands	40%	1716±94	723±118	230±12	641±06 ns	266±08
		0 %	1312±45	443±26	96±16	963±140 ns	394±19

Total nitrogen was higher in MASs than MUSs in all clusters, although differences were not always significant, and a significant difference ($P<0.05$) was observed only in cluster 1; uplands and cluster 3; lowlands (Table 1). Extractable P was also higher in MAS than MUS in all clusters, but no significant amendment effect on P except in lowlands of cluster 3. Extractable K, Mg and Ca levels in soils varied in a wide range in all clusters and land classes, but a direct relationship between K, Mg, and Ca levels and amendments was not observed. Incorporation of animal manure and rates of applications did not contribute to make remarkable differences in the major nutrient levels in soils.

Soil pH in the study area showed a small variation (from 5.2-6.2) among all land classes of all clusters, and this range is suitable for potato cultivation. The incorporation of animal manure increased pH of soil in all clusters (Figure 2). However, significant differences ($p<0.05$) in soil pH were observed between MAS and MUS only in cluster 1, while no significant amendment effect on pH was observed between land classes or amendment systems of clusters 2 and 3. Further, there was no significant difference in soil pH between cattle and poultry manure based systems.

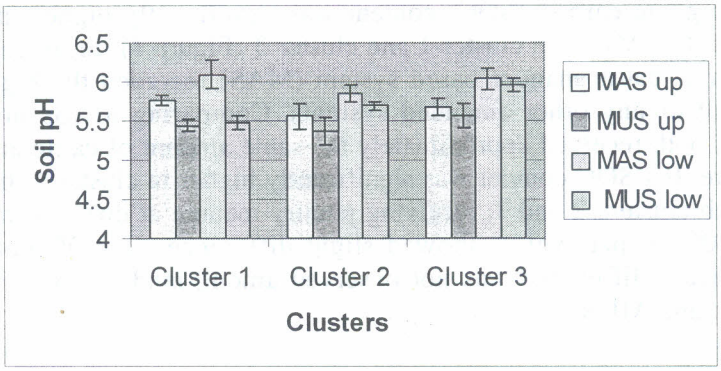


Figure 2. Soil pH in manure amended and unamended systems. Error bars indicate ± s.e. of mean of four replicates in each land class. MAS up (manure amended system, uplands), MUS up (manure unamended system, uplands), MAS low (manure amended system, lowlands), MUS low (manure unamended system, lowlands)

According to soil textural analysis, uplands of all three clusters showed brown and gray-brown loam and loam-clay. Lowland classes of all three clusters comprised brown and black clay, clay-loam and silty-clay. Further sand : clay ratio showed strong linear correlation with tuber yield in all clusters (Figure 3).

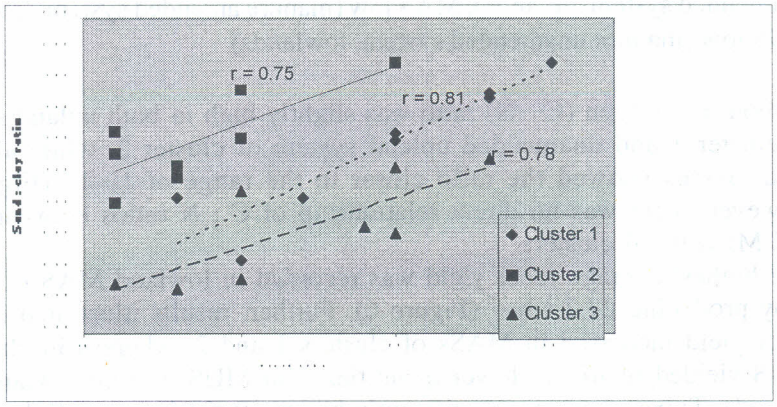


Figure 3. Correlation between sand : clay ratio and tuber yield (t ha^{-1}) in three clusters.

Soil organic carbon (SOC) content was significantly higher ($p<0.05$) in MASs than MUSs in cluster 1 and cluster 3 (Figure 4). In the lowlands of cluster 1, cattle manure based system (MAS) recorded the highest SOC content of any other amended systems. Comparing MASs in cluster 1 and 3, both received approximately the same amount of cattle and poultry manure, but SOC content was significantly higher in cluster 1 than cluster 3. Both clusters 2 and 3, receiving poultry manure at different rates (25% and 40% respectively), showed slight differences in SOC content, but significant difference was not observed among land classes, clusters or MASs and MUSs.

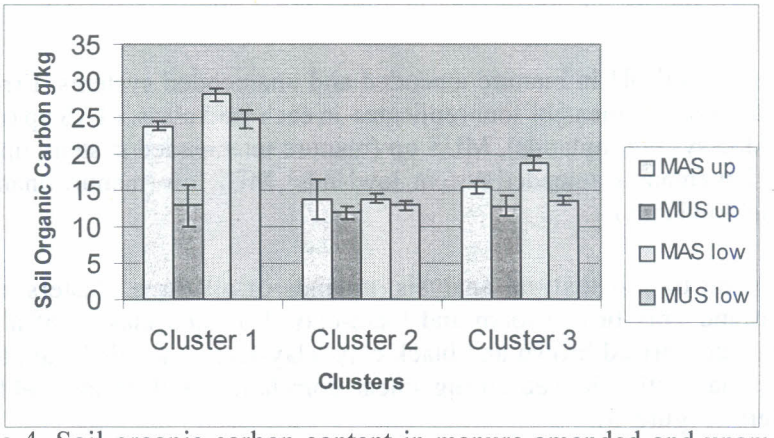


Figure 4. Soil organic carbon content in manure amended and unamended systems. Error bars indicate ± s.e. of mean of four replicates of each land class. MAS up (manure amended system, uplands), MUS up (manure unamended system, uplands), MAS low (manure amended system, lowlands), MUS low (manure unamended system, lowlands)

Carbon to nitrogen (C : N) ratio was slightly high in both upland systems of cluster 1 and unamended upland system of cluster 2, while all other land classes showed the ratio closer to the range of 10-12 (Figure 5). However, there was no direct relationship of C : N ratios between MAS and MUS in all clusters.

The highest average tuber yield was recorded in lowland MAS of cluster 1 by producing 27.2 t ha^{-1} (Figure 6). Further, results illustrated that the tuber yield increased in MASs of clusters 1 and 2, whereas in cluster 3, MAS yielded relatively lower quantities than MUS in both lowlands and uplands. Tuber yield was significantly higher ($P<0.05$) in MAS than MUS only in lowlands of cluster 1. However, there was no significant difference in the tuber yield between MAS and MUS in all other land classes or clusters. When comparing all land classes relatively high yield was recorded in lowland grown potato in all clusters.



Figure 5. C : N ratios of manure amended systems and unamended systems. MAS up (manure amended system, uplands), MUS up (manure unamended system, uplands), MAS low (manure amended system, lowlands), MUS low (manure unamended system, lowlands)



Figure 6. Potato tuber yield in manure amended systems and unamended systems. Error bars indicate ± s.e. of mean of four replicates in each land class. MAS up (manure amended system, uplands), MUS up (manure unamended system, uplands), MAS low (manure amended system, lowlands), MUS low (manure unamended system, lowlands)

Incorporation of animal manure always showed a cost reduction, ranging from 3 to 7.2 % of production costs. When the rate of manure amendment increased, reduction in production costs also increased. Both cluster 1 and cluster 2, recorded higher average yield in MASs than MUSs while cluster 3 showed an opposite relation i.e. MUSs recorded slight increase in average yield in both uplands and lowlands (Table 2).

Table 2. Production costs of potato in manure amended and unamended systems. MAS (Manure amended system), MUS (manure unamended system)

	Cluster 1		Cluster 2		Cluster 3	
Cost (LKR)	*MAS*	*MUS*	*MAS*	*MUS*	*MAS*	*MUS*
Uplands						
Fertilizer	73125	87500	68750	87500	57500	87500
Other	450000	452000	417500	420000	425000	421500
Total	**523125**	**539500**	**486250**	**507500**	**482500**	**509000**
Unit (per ton)	21136	24804	24620	27432	23827	24438
Average yield (t ha^{-1})	24.75	21.75	19.75	18.50	20.25	21.00
Benefit : cost ratio	1.98	1.69	1.62	1.45	1.67	1.65
Reduction in production cost (%)	3.04%		4.18%		5.20%	
Lowlands						
Fertilizer	73125	87500	68750	87500	57500	87500
Other	380000	382500	377500	381000	378000	382150
Total	**453125**	**470100**	**446250**	**468500**	**435500**	**469650**
Unit (per ton)	16628	19789	20284	22309	17958	18600
Average yield (t/ha)	27.25	23.75	22.00	21.00	24.25	25.25
Benefit : cost ratio	2.40	2.02	1.82	1.65	2.06	1.98
Reduction in production cost (%)	3.59%		4.74%		7.27%	

The results showed that the benefit : cost ratio was always higher in MASs than MUS in clusters1 and 3, while it was almost same in both classes of uplands of cluster 3 (Table 2). Other characteristic feature observed in this study was an always higher benefit : cost ratio being recorded in lowland cultivations in *yala* season. When comparing benefit : cost ratios between MAS and MUS in these three clusters, cluster 1 showed a greater increase in benefit : cost than the other two clusters.

Discussion

Significant differences in major nutrient levels were not observed between manure amended soils and unamended soils, but soil organic carbon (SOC) content and pH have been increased in all land classes of amended systems. However, all nutrient levels of the soils in both MAS and MUS have been increased by continuous application of fertilizers and cropping practices.

To characterize fertility levels of soils in potato production areas, knowledge of the relationships between rates and type of fertilizers used, tuber yield and residual nutrients are essential (Li *et al.*, 2006). The high values of soil nutrients have been recorded in all land classes due to the excess amount of fertilizer application at each growing season, and also due to accumulation of residual nutrients and chemicals released from crop residues (Kudagamage, 1998; Sims *et al.*, 1998; Rosan,1991). This high nutrient status reflects both amended and unamended cropping

systems can provide sufficient amount of essential nutrients for growing plants. Therefore, application of combined fertilizers, chemical and animal manure to potato cropping is a successful method while reducing the production costs. Further, incorporation of animal manure can provide the required amounts of nutrients, needed for optimal plant growth and nutrient use efficiency for potato crops, and thereby minimize the need for expensive chemical fertilizers (Janseen and Willigen, 2006).

Soil pH is significantly higher ($P<0.05$) in MAS than MUS in cluster 1 where cattle manure was incorporated into fertilizers. In all clusters soil pH was higher in lowland cropping systems than upland systems. Because, in the uplands, lands are left for fallowing for a few months, this results in soils rich in organic matter, and the acidity of the soil is relatively high due to humic acid formation during the decomposition process of organic matter. Moreover, in all cropping systems, soil pH has been recorded between 5.2 -6.2, which is in the favourable range for the potato crop (Peet, 2006).

Since pH affects the availability of major plant nutrients, N, P, K, Ca and Mg availability is relatively low in acidic soil (Biswas and Mukherjee,1994). But the addition of animal manure may increase the bioavailability of soil P (Singh and Srivastaya, 1970; Erich *et al.,* (2002); Ohno *et al.,* (2005). This study also shows that incorporation of animal manure increased extractable P in the soil. Soil organic matter is a critical factor, because it directly or indirectly affects various chemical, physical and biological properties of soils that are related to plant behaviour (Fan *et al.,* 2005). Organic carbon content differed over growing seasons and amendment systems. Manure amendment ratios were significantly correlated with SOC in all land classes. SOC was significantly high in systems, which received cattle manure and that is attributed to high amounts of cellulose and lignin in cattle manure. Erich *et al.,* (2002) and Mitchell *et al.,* (2006) reported that animal manure amended systems increased the levels of SOC in soils.

Total N content in the soils was high in MAS, but there was no direct quantitative relationship between amendment types or manure rates, and land classes. However, N content was comparatively higher in MAS than MUS in cattle manure amended lowland soils which recorded the highest mean value (2409 mg kg^{-1}). Further, C : N ratio does not show direct relation to land classes or amendments, and mostly values are well within the suitable range for potato cropping. Allison (1973) has reported that the usual ratio of carbon to nitrogen in cultivated soil is between 10 and12.

Production of comparable tuber yield was recorded in manure amended soils with low rates of fertilizers. Cropping systems that utilize animal

manure can be beneficial from an agronomic perspective by decreasing the requirement for chemical fertilizer to meet crop demand (Ohno *et al.*,2005).This may be due to an improved nutritional environment in the rhizosphere and efficient utilization by growing plants and tubers. This is in agreement with reports on enhancement of physiological activities of potato plants with the addition of organic manure (Singh *et al.*, 1970).

Better understanding of agronomic practices has been established in all clusters. Vegetables, such as beans, cabbage, and tomatoes are rotated with potatoes in upland planting systems, while potatoes follow rice, and then vegetables are rotated in lowland planting systems. The benefits of a good crop rotation are increased organic matter, nitrogen supply and improved structure of soils.

In this study area manure amendment is practiced as a combination of animal manure and chemical fertilizer, and has been continuing over several years along with crop rotation leading to soils which are rich in the required chemicals for crop growth. According to the results, there is a strong positive correlation (Figure 3) between potato tuber yield and the sand : clay ratio of soils, but there was no significant correlation between yield and all other nutrient levels. This is due to the presence of excess nutrient levels in both amended and unamended systems. The results of this study reveal that the benefit of the integrated use of manure and chemical fertilizers when both materials are used in combination, leads to an interaction and results in a satisfactory tuber yield while decreasing the production costs.
Farmers' ultimate goal is to increase the benefit : cost ratio, and this study demonstrated that integration of organic and conventional farming systems is a successful attempt to reach their goal. Potato yield obtained from cattle manure and poultry manure integrated farming systems are comparable to those obtained from chemical fertilizers alone, and the combination of chemical fertilizer and manure application seems sufficient to produce satisfactory yields. It is also evident that continuous fertilizer and manure application results in nutrient accumulation. Use of crop management systems, which utilize cattle and poultry manure to substitute part of the fertilizer requirements of the crop is cost-effective by decreasing the quantity of purchased chemical fertilizer inputs. Monitoring changes in soil quality regularly is a vital factor to improve and maintain soil fertility levels for sustainable potato production.

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