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Comparative Assessment of Soil Chemical Characteristics in Two Contrasting Vegetable Cultivation Systems of Sri Lanka

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ABSTRACT

Diagnosing soil fertility levels in intensively cultivated vegetable systems in Sri Lanka is essential to supply plant nutrients in a complete and balanced manner minimizing environmental pollution. The objective of this study was to assess soil chemical properties in two contrasting intensive vegetable cultivating systems in the central highlands of Sri Lanka. Study was conducted in vegetable-potato-vegetable system in Nuwara Eliya region (NE) and vegetable-paddy-vegetable system in Marassana region (M). Soils collected from randomly selected farmer fields (n=100) were analyzed for various chemical properties and compared with optimum values established elsewhere. The pH buffer capacity, electrical conductivity, total carbon and nitrogen contents were significantly high in soils of NE ($P<0.05$). From among measured plant available nutrients, P, K, Mg, S, and Zn were significantly high ($P<0.05$) in NE but Cu was not significantly different between the two systems. About 90-100% of farmer fields exceeded the optimum P, K, Mg and Ca levels in both regions but the K:Mg ratios were within the optimum levels. Almost all fields had lower than optimum S, Cu and Zn contents suggesting the need for their application to obtain higher productivity levels. Available P content is increasing at an alarming rate due to indiscriminate organic and synthetic fertilizer use and had already exceeded the environmental threshold levels in most soils (98% in NE and 84% in M). We concluded that site-specific integrated nutrient management strategies are needed for sustainable vegetable production in the two systems and the strategies must be system specific.

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INTRODUCTION

Intensive vegetable cultivation is generally characterized by application of large quantities of fertilizer, frequent irrigation, repeated tillage operations and limited crop rotation with short lived crops (Alliaume *et al.,* 2013; Norris and Congreves, 2018). Owing to the characteristic shallow root system, these crops obtain nutrients from a small volume of soil but remove higher amount of plant nutrients from the cropping field through biomass yield within a short period of time (Jeewanthan *et al.,*1995; Wijewardhana, 2000a). These restless management practices and different unbalance inputs have created vulnerability to soil degradation in these systems. Hence, soil quality in vegetable cropping systems has been seriously threatened in many parts of the world (Willekens *et al.,* 2014).

Judicious application of plant nutrients is important for a sustainable vegetable production system. Because of ever-changing vegetable varieties and difficulties in the accurate management of water and nutrients, farmers tend to use large amounts of fertilizer as an insurance dose to obtain maximum yields (Ju *et al.,* 2007; Yan *et al.,* 2014). Application of large amounts of synthetic inorganic fertilizer (SF) has resulted in accumulation of P in some vegetable growing soils elsewhere in the world (Liang *et al.,* 2013). Similar scenario was observed under Sri Lankan conditions as well, where the level of CF applied by the farmers to exotic vegetables was two to three times the quantity recommended by Department of Agriculture (Kendaragama, 2006). In addition to SF, the application of high levels of organic amendments (OA) in vegetable cropping systems in Sri Lanka has been observed (Jeewanthan *et al.*, 1995; Latheef and Maraikar, 2003; Upekshani *et al.,* 2018).

Many suspect that current nutrient management practices adopted in intensive vegetable production systems could lead to N and P pollution in nearby aquatic bodies (Yan *et al.,* 2014). Continuous organic manure application in some vegetable cultivating soils of Sri Lanka has resulted in P and K accumulation, emphasizing the importance of regular monitoring of organic manure usage and soil quality to sustain soil fertility and productivity (Latheef and Maraikar, 2003). Most of the vegetable crops require moderately acidic to neutral pH values (5.5-7.0) for normal growth and development (Liu *et al.,* 2015). Excess N fertilizer use has been linked to an increase in soil acidification in vegetable cultivating fields in China has been attributed to (Zong *et al.,* 2009). Excessive use of N fertilizer in intensive vegetable cultivation areas may also cause environmental issues such as groundwater contamination.

About 50% of the vegetable production in Sri Lanka is concentrated in the central highlands. Vegetables are cultivated intensively in this region in rotation with rice or potato (Kendaragama, 2006). Majority of the vegetable cultivating farmers in Sri Lanka are full time vegetable producers therefore yield maximization for generating high income is their main objective. Vegetable cultivating systems in Nuwara Eliya (NE) in the up-country wet zone and Marassana (M) in the mid country intermediate zone of Sri Lanka have been identified as vegetable-potato-vegetable and vegetable-paddy-vegetable rotations, respectively (Kendaragama, 2006). Potato and vegetables are mainly cultivated for commercial purposes in NE, but only vegetables are grown as a cash crop in M. It was observed that the type of vegetables predominantly cultivated in the two regions are also different (Upekshani *et al.,* 2018) and hence the quantity of agricultural inputs also varied significantly.

In vegetable cultivation, the surface soil layer (0-20 cm) is subjected to greater disturbance than in paddy (Wang *et al.,* 2014; Wang *et al.,* 2019). Frequent tillage operations could expedite decomposition of SOC (Pinheiro *et al.,* 2004; Treoni *et al.,* 2010). Total soil organic carbon stocks have been decreased when land use is converted from paddy to vegetable due to decrease of root biomass, plant residue return, and excessive use of inorganic nitrogenous fertilizer application (Wang *et al.,* 2014). The growth conditions required for rice are also quite different from those required for upland crops. Rice will grow best under puddled and anaerobic soil conditions, whereas upland crops require un-puddled and aerobic soil conditions (Chen *et al.,* 2012). Such information suggests that the rice - upland crop rotation should have a less negative effect on soil chemical properties compared to intensive upland monoculture.

Soil chemical properties in vegetable cultivating systems in Sri Lanka have been studied in isolation. Accumulation of P, K and an increase in soil acidity are general observations in vegetable cultivating soils in NE (Ariyapala and Nissanka, 2006; Amarawansa and Indrarathne, 2010; Abayapala *et al.,* 2014; Hemamali *et al.,* 2019; Silva *et al.,* 2020) and M (Silva *et al.,* 2020). However, there is no information available on the differences in important chemical properties in two cultivating systems. Such information is vital to suggest appropriate soil management technologies for vegetable cultivating soils in the central highlands of Sri Lanka. Hence, the objective of this study is to quantify and compare soil chemical quality parameters in two intensively cultivated vegetable cropping systems in Sri Lanka, and to assess their impact on soil productivity and environmental quality.

MATERIALS AND METHODS

Study area

The study areas were selected from five Agrarian Services Divisions (ASD) in NE (*i.e.*, Nuwara-Eliya, Kandapola, Ragala, Nildandahinna and Mandaramnuwara) and from Marasssana ASD where intensive vegetable cultivation is practiced in Sri Lanka. Based on farmer data available at ASDs, 50 farmlands, each from NE and M, were randomly selected, representing Magoda, Meepilimana, Jayawardhanapura, Kande-ela, Kalukale, Palalpathana, Mahakudugala, Kandapola, and Mandaramnuwara villages from NE and Marassana, Damunugolla, Meeruppa, Alekewela, Galagoda, Kirawanagoda, Kandewela and Bawlana villages from M for soil sampling (Figure 1).

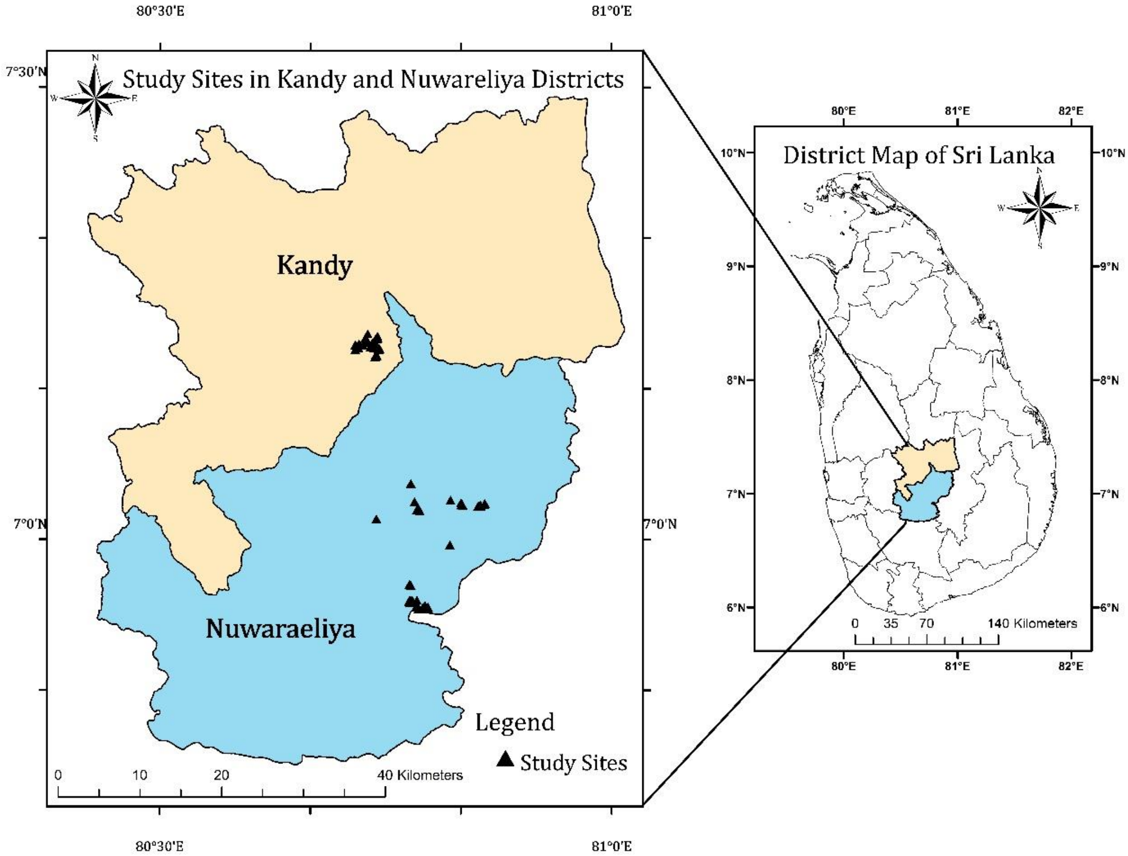

Figure 1. Distribution of the selected farmer fields in Nuwara Eliya and Marassana regions in the Nuwara Eliya and Kandy districts of Sri Lanka.

The two study areas represented two agroecological regions and also having two contrasting cropping systems of Sri Lanka. Farmer fields in NE are located in the up country wet zone agro-ecological area (WU3), which receives about 1375 mm of 75 % expectancy of average annual rainfall and belongs to NE land system with soils equivalent to great group Hapludults (Dasanayake and Hettiarachchi, 1999; Dasanayake and Senarath, 1999; Somasiri and Nayakekorala, 1999) and the upcountry intermediate zone (IU2) which receives >1400 mm of 75 % expectancy of average annual rainfall and belongs to the Rikillagaskada-Ragala land system with the same great group (Punyawardena, 2005; Somasiri, 2005). Farmer fields in M are in the mid country intermediate zone (IM3c) with >900 mm of 75 % expectancy of average annual rainfall, and belongs to the Thalathuoya–Marassana land system with soils equivalent to great group of Rhodustalfs (Dasanayake and Senarath, 1999; Somasiri, 2005; Silve *et al.,* 2005). According to the traditional classification, soils in NE and M are red yellow podzols (RYP) and reddish brown latosols (RBL), respectively.

Lands in NE, were cultivated with vegetables for two seasons while the *Maha* season was cultivated with potato. In contrast, farmers in M cultivate their lands for two seasons with vegetable and *Maha* season with paddy in rotation. Vegetable cultivation in both systems were intensive and highly commercialized and lands with more than 50 years of cultivation history (Kendaragama, 2006; Upekshani *et al.,* 2018). The main vegetables that are being cultivated in NE are high value crops such as carrot, cabbage, beet, leeks, knol-khol, cauliflower, and lettuce. The main crops in M were tomato, bitter gourd, snake gourd, luffa, beans, cabbage, wing bean and pumpkin.

Soil sampling and analyses

A composite soil sample was collected using a Gouge auger from the top soil (0-20 cm) in each randomly selected farmer field (n=100) before tillage operations for the cultivation of next vegetable crop. Samples were air-dried and sieved using 2-mm sieve before the laboratory analysis of chemical properties.

Total organic carbon (TC) and total nitrogen (TN) contents were determined using a CN analyzer (SKALAR Primacs $^{SNC-100}$). Soil pH and EC of each soil sample were determined in 1:2.5 and 1: 5 soil /water suspension using a pH meter (Eutech pH 700) and EC meter (Eutech COND 6+), respectively. Available P, K, Mg, Cu and Zn were extracted using the Mehlich-3 extractant (Mehlich, 1984). Phosphorus content in the extracts was determined using a spectrophotometry based ascorbic acid method (Murphy and Riley, 1962) and K was measured using flame photometry (Jenway PFP 7). Other nutrients such as Mg, Cu and Zn were measured using an atomic absorption spectrophotometer (Agilent 240 ZAA). pH buffer capacity (Rowell,1994), and CEC (using unbuffered salt extraction method) were measured. Sulphur content was measured using turbidimetric method using a Shimadzu UV-1900 spectrophotometer as outlined in Dharmakeerthi *et al.,* 2007.

Data analysis

Data tabulation, processing and calculations were done using Excel 2010. Outliers were identified using 1.5 times the Inter Quartile Range (IQR) and removed from data set when it became an influential data point in correlation analysis. The data were tested for the normality using normality plots and Shapiro-Wilk test. The means of soil properties in two regions were compared using one way ANOVA at $p< 0.05$ and correlations among properties were tested using Pearson correlation coefficient. All statistical analysis were conducted using SPSS statistical software (IBM Inc., 2009).

RESULTS & DISCUSSION

Variability of soil properties

Descriptive statistics of the studied soil properties are given in (Table 1 and 2). Variability of soil properties can be classified using coefficient of variation (CV%) where the lowest was being <10 %, moderate 10-50% and highest was being >50% (Jacobsen, 1985). Most of the soil properties were moderately variable in this study. However, the lowest CV% was observed for soil pH, while EC, TN, S, Mg and Cu showed the highest variability >50 %. The high variability of these parameters could be due to variation in plant nutrient management technologies adopted by farmers which in turn suggests that site-specific nutrient management technologies should be encouraged to improve soil productivity (Metwally *et al.,* 2019) and efficient use of agricultural inputs.

Basic chemical properties

The pH of intensively cultivated vegetable fields in NE ranged from strongly acidic to neutral (4.02 to 6.82) with a mean of 5.46. Similar observations were made in M where the values ranged from 3.33 to 7.58 with the mean of 5.30 (Table 1). The mean values observed in this study were similar to those found in previous studies for intensive vegetable cultivating systems in NE (Ariyapala and Nissanka, 2007; Amarawansa and Indrarathne, 2010; Abayapala *et al.,* 2014) and Marassana (Silva *et al.,* 2020). Optimum pH for vegetable cultivation ranged from 5.5 to 7.0 (Ganeshamurthy *et al*., 2016). As a result, approximately 56% and 58 % of fields in NE and M, respectively, require liming, to increase crop yields. pH buffer capacity was also significantly different in soils of the two regions, with NE soils having a mean of 35.6 mmol kg^{-1} pH^{-1} while it was 19.04 mmol kg^{-1} pH^{-1} in M soils (Table 1). pH buffer capacity of soils increases with increasing organic matter content (Xu *et al.,* 2012) and we too observed a significant positive correlation between pH buffer capacity and OC contents in soils (Table 2). NE soils contained higher OC content than that of M soil, resulting a higher pH buffer capacity in NE soils (Table 1). Application of dolomite is a common soil management practice in these areas. However, dolomite could be applied less frequently for soils in NE than for soils in M, when similar quantities of N fertilizers are used. On the other hand, NE soils might need higher rates of dolomite to increase pH by one unit. Therefore, careful evaluation of lime requirement in the two cropping systems is essential to achieve high productivity. Soil pH is an important soil quality parameter which determines nutrient sufficiency, deficiency, toxicity and crop production (Ganeshamurthi *et al.,* 2016).

Electrical conductivity (EC) value of the studied soils was significantly different between the two areas (Table 1). The mean values observed in this study were similar to the previous findings for intensive vegetable cultivating systems in NE and M (Abayapala *et al.,* 2014; Nawarathne *et al.,* 2018; Silva *et al.,* 2020). The salinity threshold of the majority of vegetable crops is low and it ranged from 0.1 to 0.25 S m^{-1} of EC in considered as saline when the EC_e in the root

Table 1. Summary of chemical properties in vegetable cultivating systems in NE and M in Sri Lanka.

Exploratory Statistic	pH		pHBC (mmol kg^{-1} pH^{-1})		EC (S m^{-1})		CEC ($cmol_c$ kg^{-1})		TC %		TN %	
	NE	M	NE	M	NE	M	NE	M	NE	M	NE	M
N	50	50	40	35	45	50	39	31	39	35	39	35
Mean	5.46	5.30	35.6	19.0	0.014	0.009	2.89	3.33	2.77	0.94	0.23	0.08
Median	5.39	5.26	36.6	18.7	0.011	0.008	2.88	3.08	2.78	0.95	0.22	0.07
Min	4.02	3.33	22.5	9.9	0.005	0.003	1.85	1.27	1.02	0.41	0.10	0.02
Max	6.82	7.58	55.1	35.1	0.042	0.032	3.98	5.61	5.03	1.45	0.44	0.35
CV%	11.7	21.1	21.3	28.6	65.0	68.9	18.4	33.6	33.5	28.7	30.4	75.0
Sig.†	ns		***		**		ns		***		***	
Optimum	5.5-7.0				0.1-0.25							

† ** and *** indicates the significance levels at p<0.01 and 0.001 probability levels, respectively
ns – not significantly different at 0.05 probability level
Threshold for pH and EC were extracted from Ganeshamurthy *et al.,* 2016 and Machado *et al.,* 2017, respectively

zone exceeds 0.4 S m^{-1} (Machado and Serralheiro, 2017). The electrical conductivity of this study was measured with 1:5 soil: water suspension. But after the conversion of these values to EC_e using equations developed by Kargas *et al.* (2018), average EC_e values were 0.081 Sm^{-1} in NE and 0.048 Sm^{-1} for M. About 75 % of the farmer fields in NE and 92% in M has EC values below 0.1 S m^{-1} level and only 8.5 % of the farmer fields in NE exceed the EC level of the salinity threshold for vegetables (>0.25 S m^{-1}) may be due to overapplication of SF. However, none of them exceeded that threshold level in both regions (Table 1). Very low EC values in the studied soils is expected due to leaching down of soluble salts with heavy monsoon rains, despite application of large quantities of chemical fertilizers.

CEC was not significantly different between the two cropping environments. CEC levels were less than 5 $cmol_c$ kg^{-1} in most of the sites studied; the mean CEC in NE was 2.89 and it was 3.33 $cmol_c$ kg^{-1} for M. The mean values observed in this study deviated from previous findings on intensive vegetable cultivating systems in NE, and were greater than these values. However, low CEC values were common for acidic soils in the tropical region (Withana and Kumaragamage, 1993; Kumaragamage and Indrarathne, 2011). In a study conducted on forest garden soils in Kandy district, Siddique *et al.* (2007) reported much lower CEC values (0.8 $cmol_c$ kg^{-1} and 0.48 $cmol_c$ kg^{-1}) than those observed in this study. These differences could partly be attributed to the differences in methodologies adopted in addition to site-specificity. Yunan *et al.* (2018) concluded that the contents of clay, silt and OM in soils are positively correlated with CEC, while the content of sand is negatively correlated in agricultural soils of China. However, CEC was not correlated with any other chemical properties in this study (Table 2), probably due to very narrow range observed in these soils.

Table 2. Pearson correlation metrics for soil properties

	pH	pH BC	EC	CEC	C	N	P	K	Mg	S	Cu
pH BC	0.387***										
EC	-0.012 ns	-0.295*									
CEC	0.125 ns	-0.032 ns	0.090 ns								
TC	0.191 ns	0.852 ***	0.303 *	0.010 ns							
TN	0.109 ns	0.785 ***	0.353 **	-0.049 ns	0.942 ***						
P	0.111 ns	0.628 ***	0.344 **	-0.007 ns	0.626 ***	0.556 ***					
K	0.121 ns	0.527 ***	0.213 *	-0.099ns	0.509 ***	0.565 ***	0.514 ***				
Mg	0.414 ***	0.336 **	-0.132 ns	0.183 ns	0.345 **	0.189 ns	0.311 **	-0.018 ns			
S	0.003 ns	0.602 ***	0.427 ***	-0.048 ns	0.667 ***	0.680 ***	0.476 ***	0.399 ***	0.201 ns		
Cu	0.124 ns	0.230 *	0.048 ns	-0.047 ns	0.322 **	0.257 *	0.102 ns	0.032 ns	0.293 *	0.278 *	
Zn	0.357 **	0.785 ***	0.240 ns	-0.061 ns	0.759 ***	0.714 ***	0.669 ***	0.544 ***	0.289 *	0.229 ns	0.229 ns

Significance: *, ** and *** indicates at p<0.05, 0.01 and 0.001 probability levels respectively

Total organic carbon percentage of vegetable-potato rotation in NE was significantly higher (2.77±0.94) compared to that of vegetable-paddy system in M (0.94±0.27) as given in Table 1. One of the major reasons for higher OC contents in NE soils is the application of about 40 Mg ha^{-1} of fresh cattle manure or 10 Mg ha^{-1} of poultry manure prior to the potato cultivation (Upekshani *et al.,* 2018, Maraikar *et al.,*1996; Maraikar and Amarasiri, 1989; Wijewardena,2000a; Ariyapala and Nissanka, 2006). The OC values in M cropping systems are very low probably due to frequent tillage operations (Golchin and Asgari., 2008) and/or low application of organic amendments in M (Upekshani *et al.,* 2018). Patric *et al.,* (2013) proposed lower and upper limits of SOC contents for tropical agroecosystems using soil clay contents; 1 - 1.5% for soils with about 4% clay and 3.5 - 4.4% for soils with 38% clay. In this study almost all studied soils had clay contents greater than 4 % (data not presented) which suggests that the observed OC values in M are very low. Therefore, for sustainable vegetable cultivation through improved soil fertility in these areas, the application of organic amendments should become the rule rather than the exception. TOC in soils was positively correlated with measured nutrient contents (Table 2). This study highlights that long term application of OA at higher rates could increase the availability of plant nutrients in an intensively cultivated vegetable growing systems.

Status of plant nutrients

A moderate level of variability (CV is 10 – 50%) was observed in available plant nutrient contents in both cropping systems. Vegetable cultivating soils in study areas deviate from the optimum values for many nutrients (Figure 2) as reported by Kumaragamage and Indraratne (2011). Soils in NE recorded higher nutrient contents compared to soils in M for all nutrients measured in this study other than Cu. All soils in NE and more than 90% of the soils in M recorded available P contents that were far higher than the optimum values (Figure 2a). All soils analyzed in the two regions also recorded higher exchangeable K contents than the optimum level (Figure 2b) (Portch and Hunter, 2002). Mg content also expresses similar observation with 88% in NE and 98 % in M soils exceeding the optimum concentrations (Portch and Hunter, 2002). However, the available S, extractable Cu and Zn in all studied soils were below the optimum and shows very low values (Figure 2d, e, f).

Total N content

The total nitrogen content of studied soils was low but significantly different in the two systems (Table 1) following the trend in OC content. These values are in accordance with the values reported by the others for vegetable cultivating soils in this region (Abayapala *et al.,* 2014; Wijewardhana, 2001b). Very small N pools may lead to high rate of N fertilizer applications in order to obtain higher yields in the two regions. Since N use efficiency in vegetable cultivations is often <50%, heavy losses N fertilizers is also inevitable. According to Upekshani *et al.*, (2018), about 50–70% of the farmers cultivating vegetables in the two regions have applied more urea than the recommended levels. As a result, using organic amendments in conjunction with chemical fertilizer is the best way to reduce N losses from applied fertilizers in vegetable cultivating soil (Wijewardhana, 2000a).

Phosphorus availability

Mehlich 3 extractable P was very high in NE soils and it ranged from 82 to 769 mg kg^{-1}, having the mean value of 353 mg kg^{-1}. In M it ranged from 19 to 282 with a mean value of 125 mg kg^{-1} (Figure 2a). The mean values observed in NE in this study were similar to recent findings for intensive vegetable cultivating systems in NE (Hemamali *et al.,* 2019). When the two cropping systems were compared, it is apparent that P buildup was higher in potato-vegetable rotation than in the vegetable-paddy rotation. Darilek *et al.,* (2010) observed that conversion of paddy lands into intensive vegetable lands increases the P content in soil. Vegetable cultivating soils in Sri Lanka were subjected to applications of high rates of organic and inorganic inputs (Sirisena and Suriyagoda, 2018). Hence this P build up could be due to

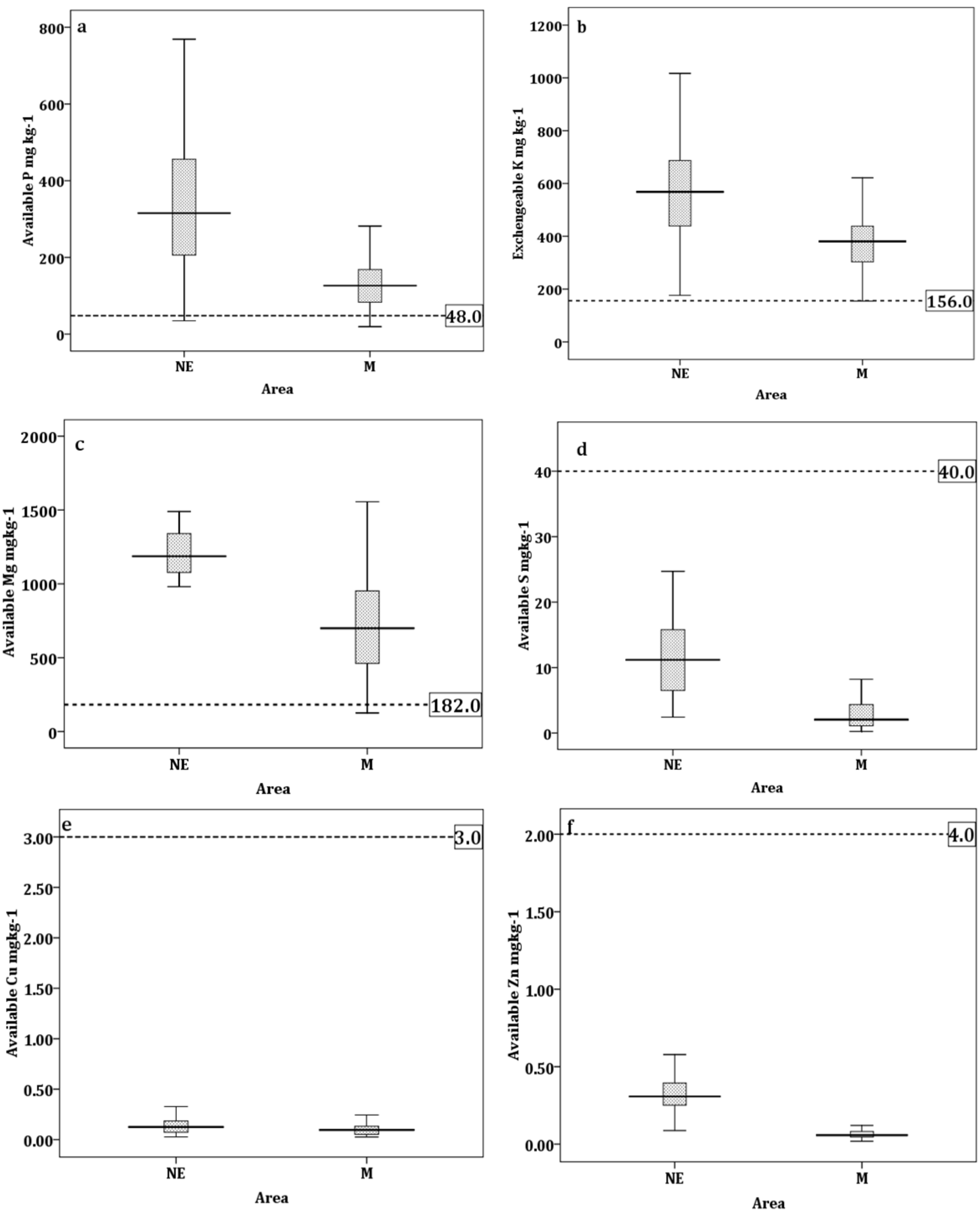

Figure 2. Comparison for variability of soil properties and nutrient levels with the optimum nutrient levels to identify the current status of Available P (a) and Extractable K, S, Mg, Cu and Zn (b-f) in two vegetable cultivating systems NE and M. Broken horizontal lines in each box plot indicate the optimum levels.

excessive application of P fertilizers and organic amendments for vegetables and potato cultivations (Wijewardhana, 1995; Wijewardhana, 2000b; Kendaragama *et al.*, 2001). Upekshani *et al.* (2018) reported that about 50 % of the NE farmers apply TSP more than the recommended level for vegetable crops grown in NE. They did not investigate the use of chemical fertilizer by farmers during the potato growing season. In general, Potato growers in NE apply 2 - 3 times the amount of chemical fertilizer recommended by the Department of Agriculture (DOA) (Kendaragama, 2003). According to Mareikar and Amarasiri (1989), increasing soil P with TSP is much more prominent than with poultry and cattle manure in vegetable cultivating systems.

Excessive TSP applications tend to accumulate P in soils. But it may not result higher productivity when it is greater than the critical values and can sometimes create nutrient imbalances in cultivating soils (Wijewardhana, 2001a; Amarawansha and Indrarathne, 2010; Hu *et al.,* 2021). Critical soil P is the value of available P that gives the optimum yield (Hu *et al.,* 2021). All studied soils recorded higher than the optimum level of 48 mg P kg^{-1} as suggested by Portch and Hunter (2002) or 30 mg kg^{-1} by DOA despite methodological differences. We used Mehlich 3 solution to extract plant available P while DOA guideline for P availability is based on 0.5N $NaHCO_3$ extracted P. Porch and Hunter. (2002) used an extractant similar to that of Mehlich-3.

In order to assess the P accumulation rate in the vegetable cropping systems in the central highlands of Sri Lanka, the available P content reported in intensive vegetable cultivating soils from 1985 to 2021was collected from published literature. All data used for this analysis were Olsen's P values. Data shows an alarming rate of P accumulation particularly after the year 2000 (Figure 3a) which could be attributed to 100% fertilizer subsidy which prompted farmers to use SF at their will. Phosphorus inputs from agricultural runoff is a non-point source pollutant that contributes to eutrophication of freshwater bodies (Litke, 1999). The available P values we observed in vast majority of soils in both regions are very much higher than the maximum agronomic threshold limits (60 mg P kg^{-1}) imposed in other countries aiming for environmental protection (Howard, 2006). Though the situation is critical, there are no comprehensive studies conducted in this region to quantify the amount of P loss through leaching and runoff. On the other hand, the excessive use of synthetic P fertilizers contributes to rapid depletion of nonrenewable P raw materials such as phosphate rocks (Yan *et al.,* 2014). Therefore, unless appropriate management practices and policies are imposed urgently, these soils will be a major threat to aquatic resources in the area.

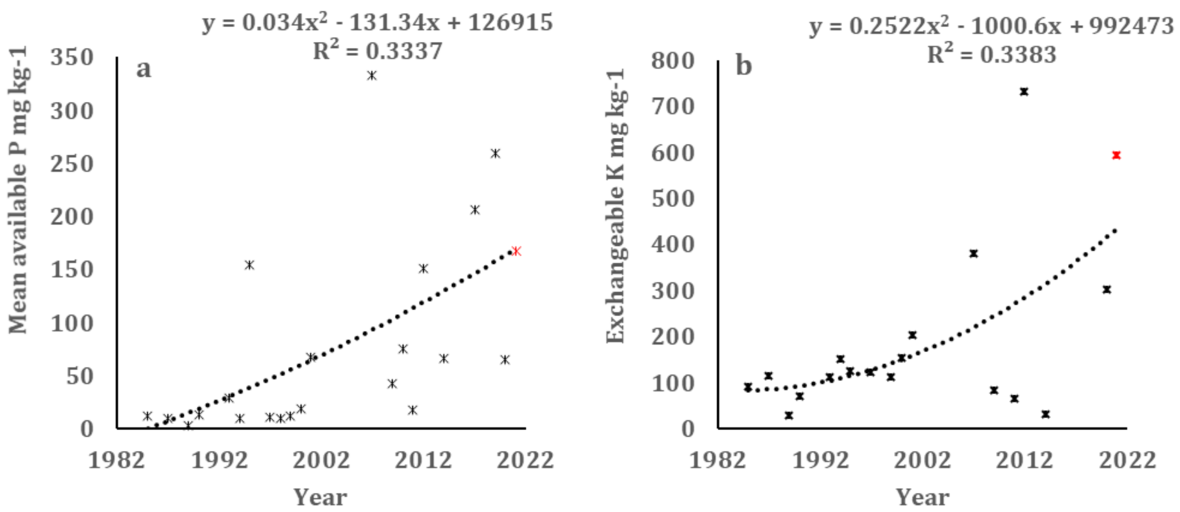

Figure 3. Variation of mean availabel P (a) and exchangeable K (b) contents in intensive vegetable cultivativating soils from 1985 to 2021 in upcountry Sri Lanka. The red dots are the mean values (n=100) of this study.

K availability

Exchangeable K content in NE soils were significantly higher with a mean value of 556 mg kg^{-1} when compared to 373 mg kg^{-1} in M. However, K content of the studied soils ranged from minimum of 176 mg kg^{-1} in NE and level that exceed the optimum (Figure 2b). The mean values observed in NE soils in this study were similar to the previous findings for intensive vegetable cultivating systems in NE (Ariyapala and Nissanka, 2006 and Abayapala *et al.,* 2014). In site-specific nutrient management, DOA recommends applying full dose of K fertilizers if soil test values are less than 160 mg kg^{-1}, 50% if they are 160-400 mg kg^{-1}, and no K fertilizers if they are above 400 mg kg^{-1} (DOA, 1995). Almost all studied soils in the two regions exceeded the optimum K level of 156 mg kg^{-1} suggested by Porch and Hunter (Figure 2b). More than 85% of fields in NE and 37 % of fields in M exceed the DOA maximum (400 mg kg^{-1}) suggesting that application of K fertilizer for such soils will not be cost effective. Very high exchangeable K levels observed in these soils could be due to the application of heavy doses of K fertilizer by the farmers, generally 3-4 time higher than the recommended level (Wijewardhana,1999; Wijewardhana and Amarasiri, 1997; Chen *et al.,* 2017), over a long period of time. According to the Mareikkar and Amaraisri (1989), the effect of poultry manure is very similar to that of MOP in increasing exchangeable K, but the contribution from cattle manure was slightly less than that of poultry manure. Farmers in NE use these two types of manure in very high quantities for long period of time. But the organic manure usage of Marassana farmers was very low (Upekshani *et al.,* 2018). If a larger amount of potassium is applied than removed by the crop, potassium is accumulated in the soil, as observed in this study, and this could lead to an antagonistic effect on the uptake of magnesium and calcium (Jacobsen,1993). The K status of vegetable cultivating soils in up country exhibits an increasing trend during the last 30 years or so (Figure 3b). Although there are no direct environmental consequences of K accumulation in soil, unlike P accumulation, ignorance of very high K levels in vegetable cultivating soils could lead to plant nutrient imbalances resulting in low productivity and low-cost effectiveness.

Availability of other nutrients

The mean Mg content of the studied soil were 954 mg kg^{-1} and 770 mg kg^{-1} for NE and M, respectively. These values were higher than the optimum level (Figure 2c) reported by Kumaragamage and Indraratne (2011). Wijewrdhana and Amarasiri (1993) reported that application of Mg increases the vegetable yield in upcountry areas, hence the importance of including Mg fertilizer in recommendations. Mehlich 3 extractable Mg values were very high in these soils which could be attributed to application of dolomite to adjust the soil pH and the application of other organic amendments such as poultry manure, broiler litter and goat manure in vegetable cultivations. Wijewardhana (2000a) observed that applying poultry manure to vegetable cultivating soils could increase Ca and Mg levels. However, increasing concentration of cation creates an inverse and adverse relationship with the availability and uptake of other cations. High concentration of Mg dominates exchange complexes over K and reduces K availability (Laekemariam *et al.,* 2018). According to Isleib, (2019), the optimum Mg:K ratio was 3.3-5.0 for the best uptake, and according to Pouch and Hunter (2002) it should be at least 1.2 but less than 4.7. In this study, the Mg:K ratio was 1.7 in NE and 2.1 in M soils, so it is within the range.

Sulphur can play a key role in augmenting the production, productivity, and quality of crops (Zenda *et al.,* 2021). The studied soils were less in extractable SO_4^{-}-S content and had a mean value of 11.5 mg kg^{-1} in NE and 2.9 mg kg^{-1} in M which were significantly different from each other. Even though extractable S is higher in NE soils, none of the fields exceeded the optimum level suggested by Pouch and Hunter (2002), for 40 mg S kg^{-1}, in both regions (Figure 2d). Wijewardhana (2001a) observed that the application of poultry manure has led to an increase in the S content of soil and therefore, S application is not necessary for vegetable crops if poultry manure is used. Usage of S containing materials and poultry manure may mask the S deficiencies in vegetable cultivating soils.

Copper and Zn are elements essential for plant growth and required in micro quantities. Soils in NE had range from 0.03 to 0.33 mg kg^{-1} Cu and from 0.15 to 1.45 mg kg^{-1} Zn, while soils in the M ranged from 0.02 to 0.25 mg kg^{-1} Cu and from 0.04 to o.43 mg kg^{-1} Zn. Extractable Cu contents in the soils of the two systems studied were not significantly different, but Zn contents were significantly different. The values for both elements were less than the optimum levels (Figure e, f). Zinc deficiency is the widest spread micronutrient deficiency in vegetable cultivating soils and could get aggravated in soils with high phosphorus applications (Rudani *et al.,* 2018), such as vegetable cultivating lands in NE and M. Previous studies have reported higher Cu content but more or less similar Zn contents (Kumaragamage and Indraratne, 2011). Although the use of Cu-based fungicides in agriculture could cause an accumulation of Cu in the upper layer (0–20 cm) of soils (Pietrini *et al.,* 2019; Keiblinger *et al.,* 2018) we could not observe high Cu levels in both systems. The soil pH in these areas were acidic, and pH has a negative correlation with the bioavailability of most of the trace elements including Cu and Zn; however, the opposite is true for the correlation between organic matter content and availability of trace elements (Silva *et al.,* 2019). Hence relatively high OC and pH could have been the reason for higher Zn values in NE compared to M. On the other hand, Cu and Zn content show a significant positive correlation with N, P, K and TOC contents in soil, and they were higher in NE compared to M (Table 2). After considering health risks, Silva *et al.* (2020) concluded that the soils used to cultivate vegetables did not exceed the maximum allowable limits (50-140 mg kg^{-1} for Cu and 150-300 mg kg^{-1} for Zn). Therefore, the studied soils have not been contaminated with Cu and Zn up to environmental risk level.

CONCLUSIONS

Vegetable cultivating systems in NE and M are intensively managed and the soil chemical properties have been highly influenced by management practices adopted in both regions. Some of the available nutrients such as P, K, and Mg in the studied soils are found in very high quantities and exceeded the optimum levels by about 2–16 (P), 0–7 (K), and 40-9 (Mg) times. However, none of the farmer fields in these two regions had the required levels of N, S, Cu and Zn for maximum productivity. Over the last four decades, the soil P and K contents have been increasing at an alarming rate in vegetable cultivating soils of the central highlands of Sri Lanka and P levels in some soils have already exceeded the environmental threshold limits by more than 10-folds. Soils in the two regions are different in their capacity to buffer the rate of acidification with soils in NE having an almost two times higher pH buffer capacity. We conclude that site-specific integrated soil fertility management strategies, with optimum nutrient levels and soil amendments, need to be developed and implemented in the intensively cultivated vegetable farming systems of Sri Lanka to ensure their economic and environmental sustainability.

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REFERENCE

Abayapala, K.M.R.D., De Costa, W.A.J.M., Fonseka, R.M., Prasannath, K., De Costa, D.M., Suriyagoda, L.D.B., Abeythilakeratne, P.D., & Nugaliyadde, M.M. (2014). Response of potato (*Solanum tuberosum* L.) to increasing growing season temperature under different soil management and crop protection regimes in the upcountry of Sri Lanka. *Trop. Agric. Res. 25*(4), 555 – 569.

Alliaume, F., Rossing, W.A., Garcia, M., Giller, K.E., & Dogliotti, S. (2013). Changes in soil quality and plant available water capacity following systems redesign on commercial vegetable farms. *Europ. J. Agronomy*. *46*,10 -19.

Amarawansha, E.A.G.S., & Indraratne, S.P. (2010). Degree of phosphorous saturation in intensively cultivated soils in Sri Lanka, *Trop. Agric. Res*. *22*(1), 113 – 119.

Ariyapala, W.S.B., & Nissanka, S.P. (2006). Reasons for an impacts of excessive fertilizer usage for potato farming in Nuwara Eliya district. *Trop. Agric. Res*. *18*, 63-70.

Chen, S., Zheng, X., Wang, D., Chen, L., Xu, C., & Zhang, X. (2012). Effect of long-term paddy-upland yearly rotations on rice (*Oryza sativa*) yield, soil properties, and bacteria community diversity. Scientific World J. *2012*, 1- 11

Chen, S., Yan, Z., & Chen, Q. (2017). Estimating the potential to reduce potassium surplus in intensive vegetable fields of China. *Nutr. Cycl. Agroecosyst*. *107*(2), 265-277. doi:10.1007/s10705-017-9835-0

Chen, Q., Zhang, X. S., Zhang, H. Y., Christie, P., Li, X. L., Horlacher, D., & Liebig, H. P. (2004). Evaluation of current fertilizer practice and soil fertility in vegetable production in the Beijing region. *Nutr. Cycl. Agroecosyst*. *69*(1), 51-58.

Darilek, J.L., Biao, H., Cheng, L., Zhi-Gang, W., Yong-Cun, Z., Wei-Xia, S., & Xue-Zheng, S. (2010). Effect of land use conversion from rice paddies to vegetable fields on soil phosphorus fractions. *Soil Sci. Soc. China*. *20*(2), 137–145.

Dassanayaka, R.A., & Hettiarachchi, L.S.K. (1999). Soils of the up country wet zone. pp.122-138. In: Mapa, R.B. Somasiri, S. & Nagarajh, S. (Eds.). Soils of wet zone of Sri Lanka: Morphology, characterization and classification. *Soil Science Society of Sri Lanka*.

Dassanayake, R.A,. & Senarath, A. (1999). Soil survey and classification. pp.23-36. In: Mapa, R.B., Somasiri, S., & Nagarajh, S. (Eds.). Soils of wet zone of Sri Lanka: Morphology, characterization and classification. *Soil Science Society of Sri Lanka*.

Dharmakeerthi, R. S., Indraratne, S. P., & Kumaragamage, D. (2007). Manual of soil sampling and analysis. Special publication No.10. *Soil Science Society of Sri Lanka*.

Ganeshamurthy, A. N., Kalaivanan, D., & Satisha, G. C. (2016). Management of vegetable crops in acid soils of India. In: Peter, K.V. (Ed.). Innovations in Horticultural Sciences. pp. 559-584. New Delhi, India.

Golchin, A., & Asgari, H. (2008). Land use effects on soil quality indicators in north-eastern Iran. *Aus. J. Soil Res*. *46*, 27–36.

Hemamali, D.D.A.E., Dissanayake, D.M.M.R., Vitharana, W.A.U., Attanayake, C.P., Dandeniya, W.S., & Balasooriya, W. (2019). Anthropogenic impact on the soil phosphorous pools in a tropical soils. Proceedings of the ISSSM-2019, 32-35.

Howard, A.E. (2006). Agronomic thresholds for soil phosphorus in Alberta: A review in Alberta soil phosphorus limits project. Alberta agriculture, food and rural development, Lethbridge, Alberta, Canada. *5*, 1-42.

Hu, Z., Ding, Z., Al-Yasi, H.M., Ali, E.F., Eissa, M.A., Elwafa, S.F.A., Sayed, M.A., Said, M.T., Said, A.A., Ibrahim, K.A.M., & Hamada, A. (2021). Modeling of phosphorus nutrition to obtain maximum yield, high P use efficiency and low P-loss risk for wheat grown in sandy calcareous soil. *Agronomy. 11*, 1-12.

Isleib, J. (2019). Understanding base saturation ratios on your MSU soil test report. Michigan State University Extension. *Michigan State University*.

Jacobsen, S.T. (1993). Interactions between plant nutrients. III. Antagonism between potassium, magnesium and calcium. *Acto. Agric. Sco. Sec. B. Soil Plan. Sci. 43*, 1-5.

Jakobsen, B.H. (1985). Soil spatial variability. Proceedings of a workshop of the ISSS and the SSSA Las Vegas, USA 30 November-1 December 1984. Nielsen, D.R. and Bouma, J. (Eds.). Geogr. Tidsskr. 4419.

Jeevanathan. B., Senevirathne, R., & Eriyagama, I. (1995). Phosphorus and potassium status of vegetable growing soils in Midcountry and Upcountry in Sri Lanka, Krushi. *Dep. of Agric. 15*(1), 17-19.

Ju a, X.T., Kou, C.L., Christie, P., Dou, Z.X., & Zhang, F.S. (2007). Changes in the soil environment from excessive application of fertilizers and manures to two contrasting intensive cropping systems on the north China plain. *Environ. Pollut. 145*, 497-506.

Kargas, G., Chatzigiakoumis, I., Kollias, A., Spiliotis, D., Massas, I., & Kerkides, P. (2018). Soil salinity assessment using saturated paste and mass soil: water 1:1 and 1:5 ratios extracts. Water. *10*, 1589,1-11.

Keiblinger K.M., Schneider, M., Gorfer, M., Paumann, M., Deltedesco, E., Berger, H., Jochlinger, L., Mentler, A., Boltenstern, S.Z., Soja, G., & Zehetner, F. (2018). Assessment of Cu applications in two contrasting soils effects on soil microbial activity and the fungal community structure. *Ecotoxicology*. *27*, 217–233.

Kendaragama, K.M.A., Lathief, M.A., & Chandrapala, A.G. (2001). Impact of vegetable cultivation in fertility status of soils in the Nuwara Eliya area. *ASDA*. *3*, 95-100.

Kendaragama, K.M.A. (2003). Soil management technology on low productivity and degraded soils in the hill country region of Sri Lanka. Proceedings of the ESAFS International Conference. *Taiwan*. pp. 173-190.

Kendaragama, K.M.A. (2006). Crop growing environment in Sri Lanka with special emphasis on plant nutrient use. *J. Soil Sci. Soc. Sri Lanka. 18*, 1-18.

Kumaragamage, D., & Indrarathne, S.P. (2011). Systematic approach to diagnosing fertility problems in soils of Sri Lanka. Commun. *Soil Sci. Plant Anal*. *42*, 2699–2715.

Laekemariam, F., Kibret, K., & Shiferaw,H. (2018). Potassium (K)-to-magnesium (Mg) ratio, its spatial variability and implications to potential Mg-induced K defciency in nitisols of Southern Ethiopia. *Agric. and Food Secur*. *7*, 1-10.

Lathief, M.A., & Maraikar, S. (2003). Studies on the performance of some vegetable crops in organic farming systems. *ASDA*. *5*, 141-148.

Liang, L.Z., Zhao, X.Q., Yi, X.Y., Chen, Z.C., Dong, X.Y., Chen. R.F., & Shen, R.F. (2013). Excessive application of nitrogen and phosphorus fertilizers induces soil acidification and phosphorus enrichment during vegetable production in Yangtze river delta, China. *Soil Use Manage*. *29*(2), 161–168.

Litke, D.W. (1999). Review of phosphorus control measures in the united states and their effects on water quality. National water-quality assessment program. water-resources investigations report. Vol. 99, No. 4007. US Department of the Interior, US Geological Survey.

Liu, G., & Hanlon, E. (2015). Soil pH range for optimum commercial vegetable production. U.S. *Department of Agriculture*. pp.1-12.

Machado, R.M.A., & Serralheiro, R.P. (2017). Soil salinity effect on vegetable crop growth management practices to prevent and mitigate soil salinization. Review. *Horticulturae*. 3(2), 30

Maraikar, S., & Amarasiri, S.L. (1989). Effect of cattle and poultry dung addition on available p and exchangeable k of a red—yellow podzolic *soil, Trop. Agric. (Colombo*). *145*, 51-58.

Marikar, S., Wijewardena, J.D.H., & Amarasiri, S.L. (1996). Improving productivity of vegetable cultivation on Ultisols of Sri Lanka. pp.1-5. Symposium proceedings of managing soil fertility for intensive vegetable production systems in Asia. AVRDC. Tainan, Taiwan.

Mehlich, A. (1984). Mehlich 3 Soil Test Extractant. A modification of Mehlich 2 extractant. Comm. *Soil Sci. Plant Anal*. *15* (12), 1409–1416.

Metwally, M.S., Shaddad, S.M., Liu, M., Yao, R.J., Abdo, A.I., Li, P., Jiao, J., & Chen, X. (2019). Soil properties spatial variability and delineation of site-specific management zones based on soil fertility using fuzzy clustering in a hilly field in Jianyang, Sichuan, China. *Sustainability*. *11*, 1-19.

Murphy, J., & Riley, J. (1962). A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim*. Acta. 27, 31-36.

Nawarathna, K.K.K., Dandeniya, W.S., Dharmakeerthi, R.S., & Weerasinghe, P. (2018). Dynamics of nitrifiers in soils of intensively vegetable cultivated areas in Sri Lanka. *Trop. Agric. Res*. *30* (3), 55 – 68.

Norris, C.E., & Congreves, K.A. (2018). Alternative management practices improve soil health indices in intensive vegetable cropping systems. A review. *Front. Environ*. Sc. *6*, 1-18.

Patrick, M., Tenywa, J.S., Ebanyat, P., Tenywa, M.M., Mubiru, D.N., Basamba, T.A., & Leip, A. (2013). Soil organic carbon thresholds and nitrogen management in tropical agroecosystems. concepts and prospects. *J. Sustainable Dev*. *6*, 31- 43.

Pietrini, F., Carnevale, M., Beni, C., Zacchini, M., Gallucci, F., & Santangelo, E. (2019). Effect of different copper levels on growth and morpho-physiological parameters in giant reed (*Arundo donax* L.) in semi-hydroponic mesocosm experiment. *Water*, *11*, 1-19.

Pinheiro, E.F.M., Pereira, M.G., & Anjos, L.H.C. (2004). Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Latosol from Brazil. *Soil Till. Res*. *76*, 79-84.

Portch, S., & A. Hunter. (2002). A systematic approach to soil fertility evaluation and improvement (Special Publ. No. 5). Hongkong, China: PPIC China Program: 30-31.

Punyawardena, B.V.R. (2005). Climate of the intermediate zone of Sri Lanka. pp 6-18. In: Mapa, R.B., Dassanayaka, R.A., & Nayakekorale, H.B. (Ed.). Soils of intermediate zone of Sri Lanka. Morphology, characterization and classification. *Soil Science Society of Sri Lanka*.

Rowell, D. L. (1994). Soil Science: Method and Application. Longman, Harlow.

Rudani, K., Patel, V., & Prajapati, K. (2018). The importance of zinc in plant growth – a review. Internat. Res. J. Nat. and *Appl. Sci. 5*, 38-48.

Siddique, I., Gutjahr, C., Seneviratne, G., Breckling, B., Ranwala, S.W., & Alexander, I.J. (2007). Changes in soil chemistry associated with the establishment of forest gardens on eroded, acidified grassland soils in Sri Lanka. *Biol. Fertil. Soils*. *44*, 163–170.

Silva, N.R.N., Attanayake, C.P., Vitharana, U.W.A., Weerasinghe, P., & Elamaldeniya, E.N.K.S. (2019). Effect of soil pH and organic matter content on availability and solubility of trace elements in vegetable growing soils of Sri Lanka. *Proceedings of the ISSSM*-2019. 28-31.

Silva, G.G.R., Dassanayaka, R.A., & Mapa, R.B. (2005). Soils of the Mid country intermediate zone. pp.118-148. In: Mapa, R.B., Dassanayaka, R.A. and Nayakekorale, H.B. (Ed.). Soils of the Intermediate zone of Sri Lanka: Morphology, characterization and classification. *Soil Science Society of Sri Lanka.*

Silva, N.R.N., Weerasinghe, P., Mayakaduwa, A., & Wakwella, P. (2020). Potentially toxic trace elements in vegetable growing soil in selected areas in Central Province of Sri Lanka, *Trop. Agric*. (Colombo). 168(1), 94-109.

Sirisena, D., & Suriyagoda, L.D.B. (2018). Toward sustainable phosphorus management in Sri Lankan rice and vegetable-based cropping systems. A review. *Agric. Nat. Resour*. *52*, 9-15.

Somasiri, S., & Nayakekorala, H.B. (1999). Climate. pp 5-13. In: Mapa, R.B., Somasiri, S., & Nagarajh, S. (Eds.). Soils of wet zone of Sri Lanka: Morphology, characterization and classification. *Soil Science Society of Sri Lanka*.

Somasiri, S. (2005). Physiography and the land form of the intermediate zone. pp. 19-52. In Mapa, R.B., Dassanayaka, R.A., & Nayakekorale, H.B. (Eds.). Soils of the Intermediate zone of Sri Lanka: Morphology, characterization and classification. *Soil Science Society of Sri Lanka.*

Treonis, A.M., Austin, E.E., Buyer, J.S., Maul, J.E., Spicer, L., & Zasada, I.A. (2010). Effects of organic amendment and tillage on soil microorganisms and microfauna. *Appl. Soil Ecol*. *46*, 103-110.

Upekshani, H.A.N., Dharmakeerthi, R.S., Weerasinghe, P., & Dandeniya, W.S. (2018). Fertilizer usage and land productivity in intensively cultivated vegetable farming systems in Sri Lanka: An analysis based on a questionnaire survey, *Trop. Agric. Res*. *30*(1), 44-55.

Wang, H., Guan, D., Zhang, R., Chen, Y., Hu, Y., & Xiao, L. (2014). Soil aggregates and organic carbon affected by the land use change from rice paddy to vegetable *field. Ecol. Eng*. *70*, 206–211.

Wang, M., Xua, S., Konga, C., Zhaoa, Y., Shia, X., & Guo, N. (2019). Assessing the effects of land use change from rice to vegetable on soil structural quality using X-ray CT. *Soil Till. Res*. *195*, 1-7.

Wijewardhana, J.D.H., & Amarasiri, S. L. (1993). Response of vegetable crops in a cropping sequence to K and Mg fertilizers in the upcountry intermediate zone. *Trop. Agriculturist*. *149*, 13-22.

Wijewardhana, J.D.H. (1995). Response of potato and vegetable crops grown sequentially to phosphorus application in an Ultisols, *Trop. Agriculturist*. *150*, 28-33.

Wijewardhana, J.D.H., & Amarasiri, S.L. (1997). Long term use of potassium fertilizer for vegetable crops in the upcountry intermediate zone. *J. Natn. Sci. Coun. Sri Lanka*. *25*(1), 59-68.

Wijewardhana, J.D.H. (1999). Contribution of phosphorus and potassium from poultry manure application to potato and vegetables grown in an Ultisols of the up country. *ASDA*. *1*, 129-136.

Wijewardhana, J.D.H. (2000a). Comparison of animal manure sources on potato and vegetable cultivation in the upcountry, *ASDA*. *2*, 357-369.

Wijewardhana, J.D.H. (2000b). Sustainable plant nutrient management in intensive vegetable growing lands in the up country of Sri Lanka, *J. Soil. Sci. Soc. Sri Lanka*. *12*, 1-13.

Wijewardhana, J. D. H. (2001a). Effect of Sulphur and poultry manure application to vegetable crops. *J. Soil. Sci. Soc. Sri Lanka*. *13*, 23-27.

Wijewardhana, J. D. H. (2001b). Fertilizer and soil amendments use on potato in relation to soil fertility in rice based cropping systems of upcountry of Sri Lanka, *ASDA, Sri Lanka*, *3*, 353-363.

Willekens, K., Vandecasteele, B., Buchan, D., & De Neva, S. (2014). Soil quality is positively affected by reduced tillage and compost in an intensive vegetable cropping system, *Appl. Soil Ecol*. *82*, 61-71.

Withana, A.K., & Kumaragamage, D. (1993). Retention of phosphorus by some surface soils of Sri Lanka. *Trop. Agric. Res*. *5*, 60-68.

Xu, R., Zhao, A., Yuan, J., & Jiang, J. (2012). pH buffering capacity of acid soils from tropical and subtropical regions of China as influenced by incorporation of crop straw biochars. *J. Soils Sediments. 12*, 494–502.

Yan, Z., Liu, P., Li, Y., Ma, L., Alva, A., Dou, Z., Chen, Q., & Zhang. F. (2014). Phosphorus in China's intensive vegetable production systems. overfertilization, soil enrichment, and environmental implications. *J. Environ. Qual*. *42*, 982–989.

Yunan, D., Xianliang, Q., & Xiaochen, W. (2018). Study on cation exchange capacity of agricultural soils. IOP *Conf. Ser. Mater. Sci. Eng*. 392.

Zenda, T., Liu, S., Dong, A., & Duan, H. (2021). Revisiting sulphur-the once neglected nutrient: it's roles in plant growth, metabolism, stress tolerance and crop production. *Agriculture*.*11*, 1-24.

Zong, S.X., Xing, Z.C., Lan, W.X., & Ji, L. (2009). Study of nitrate leaching and nitrogen fate under intensive vegetable production pattern in northern China. C. R. *Biologies*. *332*, 385–392.