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Effect of Chemical Characteristics of Soil on Orange Productivity: A Case Study of Nghe An Province, Vietnam

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Abstract: This study was conducted in orange farming area of the central Nghe An province, Vietnam to understand effect of chemical characteristics of soil conditions on orange productivity. Soil samples were collected from 102 sites in three high orange yielding districts (Quy Hop, Nghia Dan and Con Cuong) to analyze 16 chemical factors including pH, macronutrients, some micronutrients and beneficial nutrients. Dataset with 16 factors obtained by chemical analysis was examined with Principal Component Analysis (PCA) to extract combination of chemical factors characterizing soils in the study area. In addition, orange productivity data of five communes of Con Cuong district for the period 2015 to 2018 was analyzed to elucidate the relationship between soil characteristics and orange productivity. The study reveals chemical characteristics of soil and its relationship in the production of oranges in the central Nghe An province. Results of this study show that: (1) Soils in the area is characterized mostly by acidity, where one third area is extremely acidic (pH<4). This can be mainly attributed to sulphate and lower contents of Ca^{2+} and Mg^{2+} in the soil and (2) Low orange productivity in Con Cuong area is caused by extremely acidic soils with excess concentration of Al^{3+} and less concentration of P_2O_5. Occurrence of extremely acidic soils in the study area can also be attributed to washing out of exchangeable cations from steep slopes due to the soil erosion.

***Keywords*:** Soil characteristics, North Central Vietnam, Orange productivity

Nghe an province in North Central Vietnam is one of the main provinces yielding oranges, providing high benefits to farmers as orange farming is the important agri-industry in this hilly to mountainous regions. The Quy Hop and Nghia Dan are the high orange yielding districts and Con Cuong is the relatively lower orange yielding district. Yen Khe commune in Con Cuong district was selected as a model region for heritage tourism project for developing rural economy with natural resources including improving orange products by the central government in cooperation with foreign donor (JICA 2016). Soil for orange trees should ideally be loose, rich in organic matter and well-drained preferably sandy loam. Sustainable orange farming on the mountain slopes is important not only for regional economy but also for land conservation due to contribution to prevention of soil erosion, especially in humid tropical regions (Doanh and Ha 2004). Therefore, development of good practice for orange farming could indirectly contribute land conservation. Dinh et al (2004) proposed orange farming model for land conservation on the steep slope (15-20 degrees) based on the study on several slope types in Nghia Dan district.

Nature and soil characteristics are closely related with crop yields (Zhang and Zhang 2005, Martín et al 2005, Rees et al 2007). Regional soil chemical characteristics determined by Geography Institute Vietnam (GFNCV) indicate different, soil type of Con Cuong in comparison to other two orange farmlands of Quy Hop and Nghia Dan. Sandstone bed rocks are forming light yellow soils which are widely distributed in the western part and central part of province; whereas yellowish red soils on metamorphotic igneous rocks and clay beds are locally distributed in Con Cuong area. Ferralitic soils degrade quickly to acidic soil causing change in chemical composition of the soils influencing strongly on the growth of crops (Shahana et al 2016, Abidoye et al 2016). Soils in the Quy Hop and Nghia

Dan areas were analyzed acidic ranging from 3.8 to 4.7 pH where concentrations of calcium and magnesium cations (Ca2+, Mg2+) were lower than the requirement of orange trees (Nguyen 2012). With background mentioned above, 16 chemical factors were selected and analyzed, to understand chemical characteristics of soils distributing in the central Nghe An province in this study and to elucidate factors affecting low orange yields in Con Cuong district.

MATERIAL AND METHODS

Study area: The study area is hilly to mountainous central Nghe An province covering 14 communes of three districts; Quy Hop, Nghia Dan, and Con Cuong district (Fig. 1). This province is located in the tropical monsoon climate region. The average annual temperature, rainfall, quantity of solar radiation and surface evaporation in this area are 22^{0}C, 1,591.7 mm/year (400 mm/month in rainy season from August to October, and (5-40 mm/month in dry season from January to April), 1,580 hours/year and 835.2 mm/year, respectively (M&HNCV 2018).

Soil sampling Soil samples were collected from topsoil of 0 - 20 cm in depth which include 60 sites from orange farms and 42 sites from other agriculture lands and forests nearby the orange farms (Table 1). These samples were collected from April 12 to 17, 2019 in Con Cuong district and August 15 to 22, 2019 in Nghia Dan and Quy Hop districts (Fig. 2).

Chemical analysis: Soil samples were air-dried and screened to remove particles >2 mm for analysis. Organic carbon (OM) is determined by Walkley-Black (Martín 1999) chromic acid wet oxidation method. T-P and available P_2O_5 are determined by the colorimetric method and by the Oniani Method, respectively. In addition, following analytical methods were applied for other elements: flame photometry for available K_2O (Hesse 1971), atomic absorption spectrum for T-Mn, T-Zn, steamed distillation for T-N (Kjeldhal method), Baricromate method for determination of $SO4^{2-}$, Cl- Al^{3+} and Fe^{2+} with a mixture of oxalate pH = 3 (ratio 1:40), ammonium Swedish ethyl acetate method for Ca^{2+}, Mg^{2+}, K^+, Na+ (ICARDA 2013).

Orange productivity: In order to elucidate impacts related to the soil quality, Con Cuong district was selected to obtain the data on orange productivity from 2015 to 2018 as a test plot. The data was collected from Union of Farmers in Yen Khe, Bong Khe, Chi Khe, Mau Duc, Don Phuc of Con Cuong district through the local branches of the District People's Committee. In addition, interview surveys from 84 farmers, who have worked on oranges for at least four years, were conducted to obtain the information on status of orange growth and agricultural practice such as fertilizing.

Principal component analysis for characterizing soils: Principal Component Analysis (PCA) with 16 factors, which is one of the tools to interpret multivariable dataset (Alkarkhi et al 2008, Bhat et al 2014) was carried out to understand characteristics of soils distributing in three districts in central

Fig. 1. Map of Nghe An province showing soil sample locations (102 sites) of Quy Hop, Nghia Dan, and Con Cuong districts

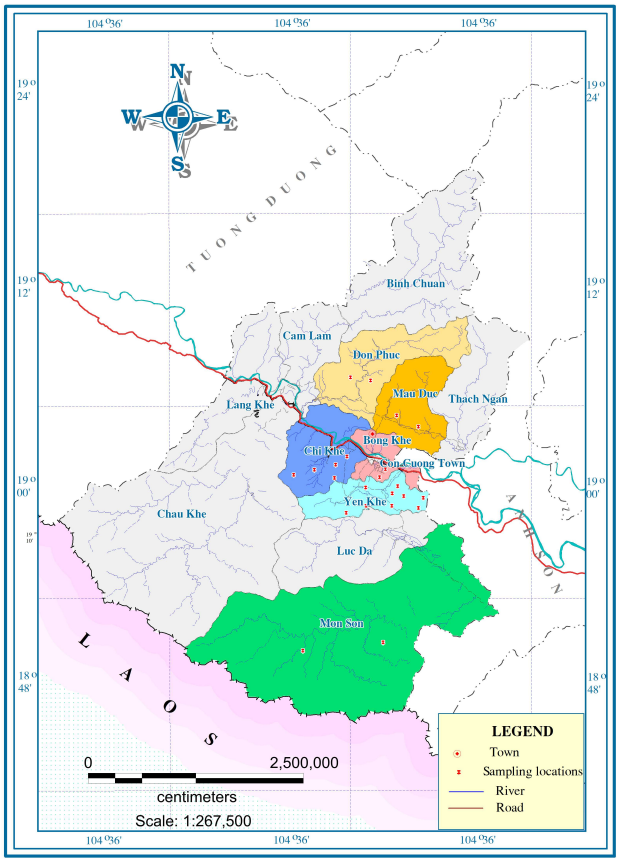

Fig. 2. Map of Con Cuong district. Soil sampling sites of six communes: Chi Khe (CK), Mau Duc (MD), Don Phuc (DP), Mon Son (MS), Yen Khe (YK) and Bong Khe (BK)

Nghe An province. PCA was carried out by EXCEL Statistics (Social Survey Research Information Co., Ltd.). The main idea of PCA is to reduce the dimensionality of a data set consisting of many variables correlated with each other.

Relation between slope gradient and pH: Slope gradient is one of the indicators for soil erosion and also soil pH. On higher slope (angle) erosion will be more likely and pH value would be less due to leaching of soluble catoins. On the contrary, significant higher pH can be observed at the foot hills of the slope where the area is flat due to accumulation of these cations. In the present study, correlation between slope gradient of sampling sites and pH was done for five communes in Con Cuong, from where orange productivity data was obtained. The slope gradient for each commune is represented in degree (Table 1).

RESULTS AND DISCUSSION

Productivity of oranges and fertilizing in Con Cuong area: Productivity is lowest of Mau Duc commune (14.8±0.2 ton/ha) and highest of Bong Khe commune (24.4±2.9 ton/ha) (Fig. 3). There is not much difference in the productivity of Bong Khe and Chi Khe communes, whereas it is almost same in case of Mau Duc and Don Phuc communes.

Fertilizing depends on climate, tree condition such as tree vigor, but standard fertilizing to orange trees aged over 10 years in Con Cuong district is not much different in all the five communes (Fig. 3 and Table 2). Some households provide super phosphate lime together with organic fertilizers after harvesting.

Principal components derived from PCA: PC1 accounting for 23.7% of total variance represents the soil acidity due to strong positive correlation of pH with PC1 and indicates increase and decrease of aluminum cation (Al^{3+}) concentration and exchangeable cation concentration; calcium and magnesium cations (Ca^{2+} and Mg^{2+}), respectively (Fig. 4). Al^{3+} concentration is negatively

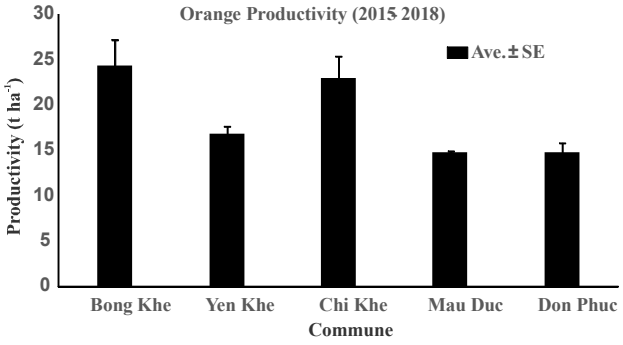

Fig. 3. Productivity of oranges from 2015 to 2018 (Mean +- SE)

Table 1. Soil sampling sites

District	Commune	Number of samples			Topography
		Total	Orange farm	Others	Slope gradient (degree)
Nghia Dan (19°13'N and 19°33'N, 105°18'E and 105°35'E)	NgH (Nghia Hong)	2	2	0	8 - 15
	NgLg (Nghia Long)	10	6	4	10 - 15
	NgLc (Nghĩa Loc)	6	2	4	12 – 15
	NgH (Nghia Hieu)	12	12	0	5 – 10
Sub-total		30	22	8	
Con Cuong (8°46'N and 19°24'N, 104°32'E and 105°03'E)	CK (Chi Khe)	7	5	2	10 – 15
	MD (Mau Duc)	2	1	1	15 – 20
	DP (Don Phuc)	3	2	1	20 – 25
	MS (Mon Son)	2	0	2	20
	YK (Yen Khe)	8	4	4	12 – 20
	BK (Bong Khe)	6	2	4	10 – 15
Sub-total		28	14	14	
Quy Hop (19°10'N and 19°29'N, 104°56'E and 105°21'E)	VL (Van Loi)	10	8	2	15 – 20
	MH (Minh Hoc)	16	14	2	8 – 15
	Xth (Xuan Thanh)	10	0	10	5 – 10
	HS (Ha Son)	8	2	6	15 – 20
Sub-total		44	24	20	
Total		102	60	42	

correlated with PC1, but Ca^{2+} and Mg^{2+} concentrations are positively correlated with it. PC2 accounting for 16.1% of total variance is positively correlated with sulphate (SO_4^{2-}) concentration which affects acidity and negatively correlated with total phosphorous (T-P) concentration. Sodium cation (Na^+) and Fe II cation (Fe^{2+}) concentrations observed increased with increase of SO_4^{2-} concentration. PC3 accounting for 14.0% of total variance represents availability of essential nutrients to plants; both total phosphorous and available phosphoric acid (T-P and available P_2O_5) concentrations and total nitrogen (T-N) concentration mainly originated from organic matter (OM) as both T-N and OM concentrations negatively correlated with PC3. PC4 accounting for 10.3% of total variance also represents availability of essential nutrients to plants; available potassium (available K_2O) concentration due to positive correlation of available K_2O with PC4. PC4 is also correlated with micro-nutrients to plants; positively correlated with chloride ion (Cl^-) concentration and negatively correlated with zinc cation (T-Zn) concentration. PC1 to PC4 contributes 67.1 percent of total variance.

Characteristics of the orange farm soils in Nghe An province: The sample scores plotted in PC1-PC2 coordinate, indicating the soil of orange farms in Nghe An province which is firstly characterised by acidity, varying from 3.51 to 6.58 with wide range of Al^{3+}, Ca^{2+} and Mg^{2+} concentrations. Extremely acidic soils contain more Al^{3+} concetration but less Ca^{2+} and Mg^{2+} concetnrations. Soil samples on PC1 axis are distributed equally both for positive and negative directions (-3.63≤PC1≤4.09), but on PC2 axis they are distributed more widely in the positive direction (-3.24≤PC2≤6.16), implying that acidity mainly is attributed to SO_4^{2-} concentration. Soil samples affected by SO_4^{2-} contain more Na^+ and Fe^{2+} concentration, but less T-P and T-Zn concetrations (Figure 5a). The sample scores plotted in PC3 – PC4 coordinate, indicating soil samples can be grouped by concentration of essential nutrients of phosphorus (T-P and available P_2O_5), nitrogen (T-N) and potassium (available K_2O). Soil samples on PC3 axis are distributed equally both for negative and positive directions (-3.83≤PC1≤3.47), but those on PC4 axis are distributed more widely in negative direction (-3.41≤PC4≤2.87, execpt for 6.85 of PC4 score), implying that the soil in the orange farms containing relatively less concetration of available K_2O is dominant in Con Cuong area (Figure 5b).

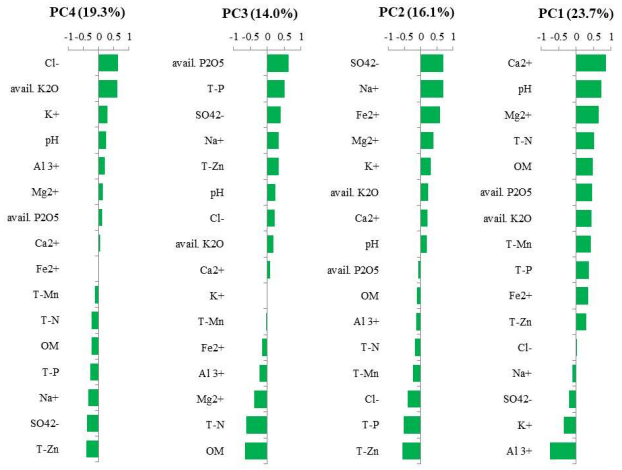

Fig. 4. Eigenvectors of PCs (PC1 - PC4)

Soils in Con Cuong district: Soil samples from Con Cuong district in the PC1-PC2 coordinate distribute from the second quadrant involving soils collected from Don Phuc and Chi Khe communes to the fourth quadrant involving soils collected from Bong Khe commune (Fig. 5a.) It implies that soils in Con Cuong range from extremely acidic to acidic (3.79±0.05 and 4.72±0.08 for Dong Phuc and Bong Khe, respectively) mainly according to the concentration of SO42-

Table 2. Standard fertilizing in orange farms, Con Cuong district

Fertilizer	Quantity (kg/ha)
Organic	
Animal mature	50 - 70
Inorganic	
Phosphorous powder	2 - 3
Synthetic NPK	2 - 3
Lime powder	1 - 1.5

Trees aged over 10 years

Table 3. Soil characteristics in Con Cuong district

Districts	pH	T-N (g/100g)	Available P_2O_5 (mg/100g)	Al^{3+} (meq/100g)	Ca^{2+} (meq/100g)	Mg^{2+} (meq/100g)	SO_4^{2-} (mg/kg)
Mau Duc	4,01	0,06	7,93	1,20	2,53	1,23	39,05
Dong Phuc	3.79±0.05^a	0.09±0.01^{ab}	3.17±0.63^a	1.00±0.06^c	2.86±0.50^a	1.15±0.06^{ab}	170.42±56.95^b
Yen Khe	4.34±0.15^a	0.08±0.01^b	5.87±0.95^a	0.33±0.13^b	3.12±0.25^a	1.04±0.01^b	37.91±1.93^a
Chi Khe	4.72±0.28^b	0.06±0.01^a	22.48±5.14^b	0.10±0.05^{ab}	4.60±0.50^b	1.28±0.09^a	225.69±50.63^b
Bong Khe	4.78±0.08^b	0.13±0.01^c	20.81±1.47^b	0.00±0.00^a	8.90±0.42^c	1.19±0.02^{ab}	46.03±2.85^a

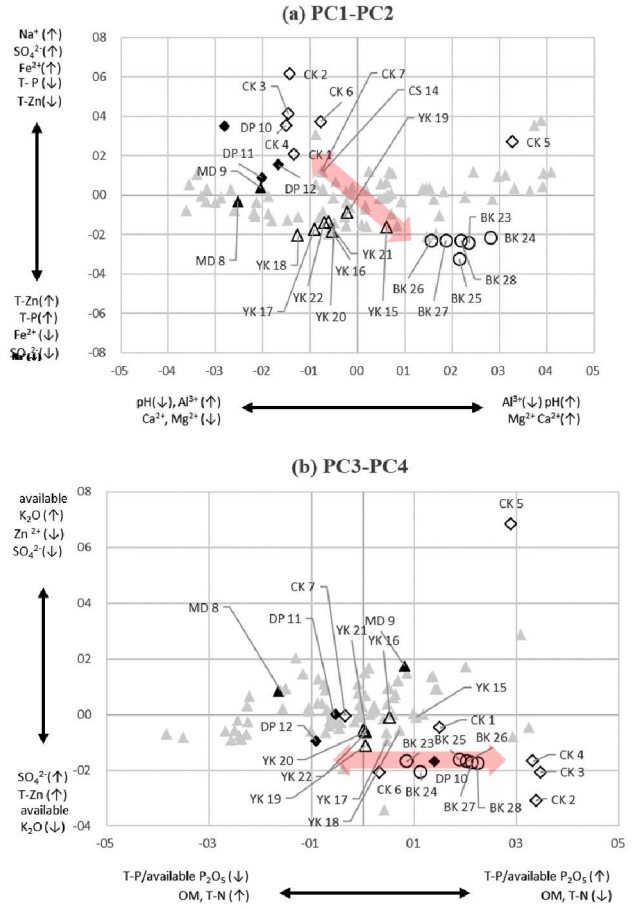

Fig. 5. Sample score plots in (a) PC1-PC2 and (b) PC3-PC4 (Red arrows indicate space distributions of soil samples from Con Cuong in PC1-PC2 and PC3-PC4 coordinates. Light gray shaded triangles indicate samples from Quy Hop district, Nghia Dan district, and Mon Son commune in Con Cuong)

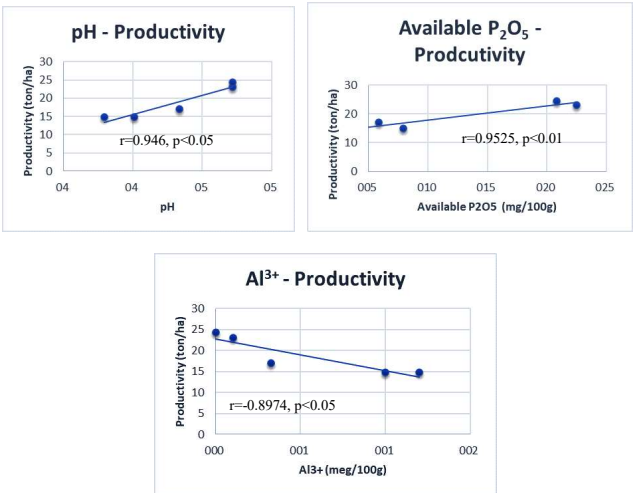

Fig. 6. Factors correlated with productivity

(170.42, 46.03 mg/kg for Don Phuc and Bong Khe, respectively). Extremely acidic soils such as those in Don Phuc contain more Al3+ concentration (1.0meq/100g) and less Ca2+. Mg2+ concentration (2.86and 1.15meq/100g, respectively) comparing to soils such as those in Bong Khe (Al3+: 0.00, Ca2+: 8.90meq/100g, Mg2+: 1.19±0.02 meq/100g). In the PC3 – PC4 coordinate soil samples in Con Cuong tend to distribute from the third quadrant to the fourth quadrant (Figure 5b). It implies that soils in Con Cuong are characterized by difference in concentration of phosphorous (T-P and available P2O5) and nitrogen (T-N), but not much difference in that of potassium (available K2O). Soils in Chi Khe is relatively rich in phosphorous (22.48mg available P2O5/100g) and poor in nitrogen (0.06g T-N/100g), but that in Don Phuc is inverse (3.17mg available P2O5/100g, 0.09g T-N/100g). The main chemical characteristics of soils of five communes: Mau Duc (MD), Don Phuc (DP), Yen Khe (YK), Chi Khe (CK) and Ben Khe (BK) (Table 3).

Orange productivity and soils in Con Cuong area: The productivity in Con Cuong district is correlated with three factors; pH, available P_2O_5 and Al^{3+}. There was positive correlation with pH and available P_2O_5 (r=0.946,), whereas negative correlation with Al^{3+} (r=-0.8974) (Figure 6). Al^{3+} is negatively correlated with pH (r=-0.932) and available P_2O_5 is positively correlated with pH (r=0.953) (Fig. 7).

Relationship between slope gradient and pH: Generally, rain water cause soil erosion which leads to removal of some exchangeable cations with flow, making soil acidic. There is a relationship between soil erosion and slope. Soil on the steeper slopes erode more rapidly with increase of flow. To verify this phenomenon happens in farmlands in Con Cuong, correlation between slope gradient as an indicator of soil erosion and pH was calculated (Fig. 8). The pH is negatively correlated with slope gradients (r=-0.968, p<0.01), which confirms that pH value decreases with increasing slope gradient.

Characteristics of orange farm soils distributing in central Nghe An province

The most distinguished characteristic of the orange farm soils in Quy Hop, Nghia Dan and Con Cuong district of central Nghe An province is low acidity. Focusing on Con Cuong district, approximately one third of the land surveyed is

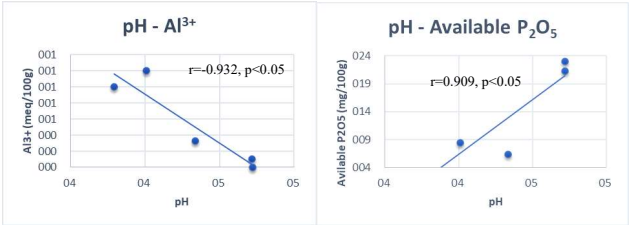

Fig. 7. Relationship pH to $Al^{3+}$and available P_2O_5

extremely acidic; less than 4 in pH (Fig. 8). PCA reveals that extremely acidic soils distribute in Mau Duc and Don Phuc commune, which are plotted in the second quadrant of PC1 – PC2 coordinate. In contrast, acidic but not extremely low pH of soils distribute in Bong Khe commune, which are plotted in the fourth quadrant of PC1 – PC2 coordinate. Samples plotted in the second quadrant contain more SO_4^{2-}, but less Ca^{2+} and Mg^{2+}, whereas ones plotted in the fourth quadrant contain less SO_4^{2-}, but more Ca^{2+} and Mg^{2+} (Figure 5a). It indicates that excess amount of SO_4^{2-} and runoff of exchangeable cations are the main cause of extremely low pH (Pagani et al 2013). pH is an important indicator for soil nutrient availability for crops. Shahana et al (2016) reported that soil of pH 5.5 to 7.0 is the most suitable for general crop cultivation and for orange cultivation appropriate value of pH is 5.8 to 6.5 (Uchida et al 2000). In Con Cuong district even though pH of soils in Bong Khe is relatively higher, mean pH is 4.78 (Table 3), the ratio of pH of 5.8 or more accounts for 12.0%. Thus, approximately 90% of the orange farm is recommended to be neutralized. The soils in Con Quong district are also characterized by nitrogen and phosphorus concentrations. Plot pattern in the P3 – P4 coordinate indicates that the soils in Con Quong vary in T-P, available P_2O_5 and OM, T-N concentrations, those factors increase and decrease inversely (Figure 5b). The soils in Chi Khe tend to contain relatively higher phosphorus but lower nitrogen, whereas ones in Don Phuc contain relatively lower phosphorus but higher nitrogen. The soils in Bong Khe are balanced in nitrogen and phosphorus concentrations. Based on this, more nitrogen and phosphorus supply than current fertilization could be required to some orange farms.

Soils in orange farms and orange productivity in Con Cuong district: Soil characteristics, slope gradients and productivities in five communes in Con Cuong district are summarized in Table 4, grouped into three soil types. The productivity (p) in Bong Khe is significantly higher than that in Yen Khe ($p<0.05$), in Mau Duc and in Don Phuc (both for $p<0.01$). Soil pH in orange farms in Con Cuong is low to extremely low even though lime powder is provided to the farms after harvesting. Soil pH in Bong Khe is significantly higher than that in Don Phuc ($p<0.05$), but not in Yen Khe, however, Al^{3+} concentration of the soils in Bong Khe is significantly lower than both the soils of Don Phuc and Yen Khe ($p<0.01$, $p<0.05$, respectively) (samples from Mau Duc

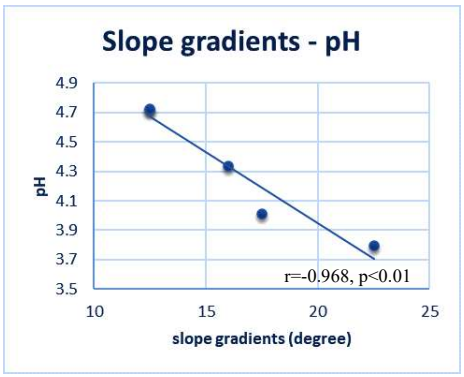

Fig. 8. Relationship between slope gradients and pH

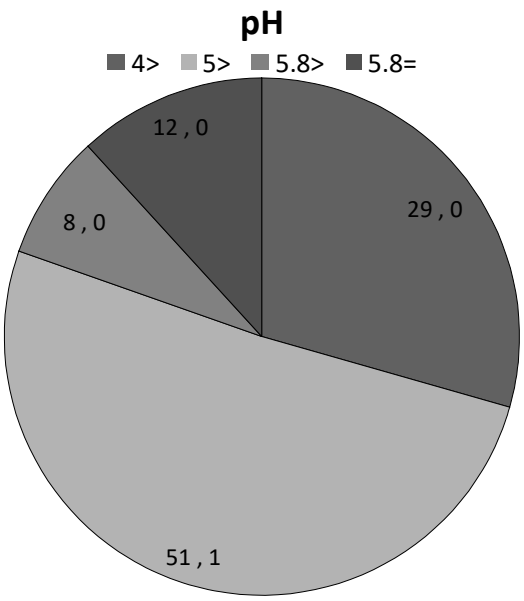

Fig. 9. Soil pH distribution in the study area (Number in the pie graph indicates percentage)

Table 4. Evaluation of orange productivity and soils in Con Cuong area

	Commune	Soil characteristics	Slope gradients (degree)	Productivity
Type I	Bong Khe	Acidic without Al^{3+}, relatively rich in Ca^{2+}, Mg^{2+}, P and N.	10 - 15	Relatively high
Type II	Chi Khe	Acidic to extremely acidic with Al^{3+}, relatively poor in Ca^{2+} and P, medium in Mg^{2+} and N	10 -15	Medium
	Yen Khe	Extremely acidic with Al^{3+}, relatively poor in Ca^{2+} and P, medium in Mg^{2+} and N	12 - 20	Medium
Type III	Mau Duc	Extremely acidic with excess amout Al^{3+}, relatively poor in Ca^{2+}, Mg^{2+} and P, poor to medium in N	15 - 20	
	Don Phuc		20 - 25	Relatively low

have not been examined by ANOVA, due to limitation of samples: two samples).pH is negatively correlated with slope gradients (r=-0.968, p<0.01), implying that soil erosion occurred more frequently on steep slopes in Don Phuc and Mau Duc (gradients: 15 -20, 20 – 25 degrees, respectively), resulting in washing out of more exchangeable cations such as $Ca^{2+}$and Mg^{2+} which makes the soil more acidic and thus promotes elution of Al^{3+}(Rout et al 2001, Kopittke et al 2016). Higher acidity in soil is not desirable as it acts poison to orange growth .Therefore, Al^{3+} elution caused by decrease of pH mostly affects orange productivity in Con Cuong area. Other factors affecting the productivity are available phosphoric acid (P_2O_5) and Ca^{2+} concentration. Concentrations of available P_2O_5 and Ca^{2+} in Bong Khe are significantly greater than those in Yen Khe and Don Phuc (p<0.01, p<0.001both to Yen Khe and Don Phuc for available $P_2O_5$and Ca^{2+}). Available P_2O_5concentration is affected by soil pH, (r=0.953, p<0.05), it was known that P_2O_5 tends to be adsorbed to soil particles under low pH condition (Cheng et al 2014).

CONCLUSION

In short, the acidity and richness of Al3 + is a prominent feature of soil in the mountainous areas of Nghe An, Vietnam. This is due to washing out of exchangeable cations from steep slopes during the process of soil erosion. The soil in orange farms in Con Cuong can be characterized by lower pH (acid) soils with concentrations of cations of Al^{3+} and Ca^{2+}, and P_2O_5, affecting the orange productivity. It can be concluded that proper pH balance is required to be maintained in soil of the farm for best production of oranges by taking suitable remedial measures to check soil erosion and also to have proper balance of cations like Al^{3+} and Ca^{2+}, and P_2O_5.

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