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Soil Chemistry Changes after N, P, and K Fertilization in a Willow(*Salix* spp.) Bioenergy Plantation[1]

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버드나무(*Salix* spp.) bioenergy 造林地內 N, P, K 施肥가 土壤化學性 變化에 미치는 影響[1]

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ABSTRACT

Chemical properties of soil(N, P, K, Ca, Na, Mg, CEC, and pH) were studied after annual additions of NH_4NO_3(336kg/ha N), treble superphosphate(112kg/ha P), and KCl(224kg/ha K) fertilizers in a willow(*Salix* spp.) bioenergy plantation. Soil samples were collected from November through December 1992 from previously established the fertilized and non-fertilized willow plantation at Tully, New York, U.S.A. in 1987. Total fertilizer additions from 1987 through 1991 were 1,680kg/ha N and 560 kg/ha P and 1,120kg/ha K. Fertilization with N, P, and K resulted in no difference in total soil N content between the fertilized and non-fertilized plots, increased soil P and K, decreased base cations (Ca^{2+} and Mg^{2+}) and soil pH, and increased soil pH with soil depth. Strong positive correlations of soil carbon to soil N, Ca, Mg, and CEC were noted. Soil C/N ratio in the study plots ranged from 9.6 to 11.2 for all treatment combinations. Significant differences in soil P, K, Ca, and pH between the fertilized and non-fertilized plots indicate that fertilization had changed chemical properties of soil in this fertilizer trial.

Key words : Biomass bioenergy, N, K, P fertilizer, Salix *spp., soil property*

要 約

목재에너지 공급을 위해 1987년 미국 뉴욕주립대 연습림에 설치된 버드나무(*Salix* spp.) bioenergy 조림지에서 연간 시비(NH_4NO_3-336kg/ha N, treble superphosphate-112kg/ha P, KCl-224kg/ha K)가 토양의 화학성(N, P, K, Ca, Na, Mg, CEC, and pH) 변화에 미치는 영향을 조사하기 위하여 1992년 11월부터 12월 사이에 분석용 토양시료를 채취하여 측정, 분석하였다. 5년간(1987~1991) 총 시비량은 1,680kg/ha N, 560kg/ha P 그리고 1,120kg/ha K 이었다. 토양화학적 특성에 미치는 시비의 영향은 다음과 같았다. 시비구와 대조구간의 토양중 총 N의 함량은 유의적인 차이가 없었으나, 유효 P와 치환성 K는 시비구에서 증가하였고, 염기성 양이온(Ca^{2+}과 Mg^{2+})과 토양 pH는 감소하였으며, 토양 pH는 토심의 증가와 함께 증가하였다. 토양중 탄소함량은 질소총량, 치환성 Ca와 Mg, 그리고 CEC와 고도의 正의 상관관계를 보였다. 토양중 평균 C/N율은 토심별 그리고 처리별에 따라 적게는 9.6에서 많게는 11.2로 분포하였다. 본 연구결과 시비는 토양화학성 변화에 중요한 영향을 미치고 있음이 나타났다.

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INTRODUCTION

Increased demand for wood fibre has led to biomass production in short-rotation intensive culture (SRIC) bioenergy plantations because they yield much more fiber per hectare than native hardwood stands under similar rotation lengths (Wittwer et al., 1978 ; Hansen and Baker, 1979). Many fast-growing hardwood genera have been assessed for their biomass production potential, with intensive efforts on those in the *Salicaceae* (Kopp et al., 1993). Willows have been extensively used in SRIC bioenergy plantations in U.S.A., Sweden, New Zealand, Ireland, and Canada because of their rapid growth, resprouting capacity, and ease of vegetative propagation (Ericsson, 1984).

Although SRIC bioenergy plantations can produce high biomass yields, continuous harvesting over several rotations may result in significant plant nutrient losses from the soil profile(Hansen and Baker, 1979 ; Ingestad and Agren, 1984). One way to replace nutrients removed in harvesting and maintain productivity under SRIC bioenergy plantations is increasing nutrient input with fertilization. Several species used in SRIC bioenergy plantations are known to respond to the applications of fertilizers(Hansen and Tolsted, 1985 ; Wittwer et al., 1978). However, fertilization is expensive, and recovery of applied nitrogen in plantation trees rarely exceeds 20%(Baker et al., 1974). Aside from tree uptake, applied fertilizer nitrogen can be immobilized in the soil, leached below the rooting zone, or converted to gaseous forms and lost(Hansen et al., 1988). Determining effective fertilizer management and minimizing fertilizer losses, and maintaining productivity require well designed research trials.

The study objective was to determine the effects of nitrogen(N), phosphorus(P), and potassium(K) fertilizers on chemical properties of soil. Also, because soil organic matter affects chemical properties of soils, the role of soil carbon(C) on chemical properties of soil in this willow plantation sites was studied.

MATERIALS AND METHODS

The field experiment was established in 1987 at the State University of New York College of Environmental Science and Forestry's Genetics Field Station near Tully, New York(42° 47′ 30″ N, 76° 07′ 30″ W) to determine the effect of willow clones and fertilization on biomass production. The soil is a Palmyra gravelly silt loam (Glossoboric Hapludalf), an agricultural soil representative of significant acreage that potentially is available for energy plantation establishment in the Northeastern United States. The soil have a gravelly loam subsoil at depths greater than 30 to 60cm and are well drained. The water table in Palmyra soils is generally at a depth of more than 91cm, but may fluctuate to less than 91cm of the surface in spring and during wet periods (Hutton and Rice, 1977).

Five willow clones that have been shown to produce high biomass yields in Canadian test plots were selected in consulation with the Ontario Ministry of Natural Resources. One hybrid poplar clone selected had performed exceptionally well in ultrashort rotations at a location near the planting site and was included for comparison purposes.

Site prepararion was done mechanically and chemically in 1986. Glyphosate(Roundup), with surfactant, was applied at the rate of 2.3kg active ingredient per hectare in late August, 1986 to kill vegetation. After confirmation of glyphosate effectiveness, the site plowed, disked and raked. To prevent weed establishment during the first part of the 1987 growing season, simazine was applied in October, 1986 at the rate of 4.5kg active ingredient per hectare.

Unrooted stem cuttings, 25cm in length, were collected from the one-year-old stems of six clones during winter 1986 from nursery stool beds at Kemptville, Ontario, Canada and stored at 0℃ before planting. Cuttings were hand planted flush with the ground, using steel planting dibbles from April 6 to 9, 1987.

Five willow clones and one hybrid poplar clone were planted at 0.3×0.3m spacing in 6×6m plots including two exterior border rows in 1987. The treatments included fertilized and non-fertilized, with three replications(6 clones × 2 fertilizer treatments × 3 replications) with a total of 36 plots providing 256 measurements per plot. A split-plot design with three replications per treatment for the main-plot factor was employed(Peterson, 1985). Fertilization treatment was the main-plot factor and clone was the sub-plot factor.

In study plots, three of the replications received annual applications of 336kg/ha N(NH_4NO_3), 112 kg/ha P(treble superphosphate), and 224kg/ha K (KCl) for five years. From 1987 to 1989 and 1991, the entire amount of P and K, and first application of 56kg/ha N was hand broadcast every three weeks after the first application. In 1990 fertilization of P and K was identical as in previous years, except N was applied as urea through an irrigation system. No fertilizer was applied in 1992.

Three soil samples were randomly taken in each plot from November to December, 1992. At each sampling point, samples were collected from 0-10cm, 10-20cm, and 20-40cm soil depths by using an Oakfield soil sampler of 10cm diameter. Bulk density samples at these depths were collected using the excavation method(Black et al., 1965).

All soil samples were analyzed by methods detailed by Bickelhaupt and White(1982). Soils were air-dried and sieved to pass through a 2mm sieve. One g soil subsamples were analyzed for organic matter concentration using the Wakely-Black wet oxidation method. Soil N concentrations were determined by the macro-Kjeldahl method. Exchangeable calcium(Ca), magnesium (Mg), sodium(Na), and K were extracted with 1 N ammonium acetate and measured using atomic absorption spectroscopy. Available P was determined by the Trough method using a 0.002 N sulfuric acid and ammonium sulfate extraction solution and stannous chloride-ammonium molybdate used to determine P concentration spectrophotometrically. The ammonium saturated method was used to determine cation exchange capacity (CEC). Soil pH was determined using a 1 : 2 (soil : water) ratio.

Analysis of variance using a split-plot design with three replications was used to test the null hypothesis that fertilization(main effect) and clone (sub-plot factor) had no significant effect on soil C, N, P, K, Ca, Mg, Na contents, and CEC concentrations and pH. Tukey's HSD test were used to statistically separate means. The SAS computer software system was used in this study(SAS Institute Inc. 1985). Test of significance were at alpha=0.05 unless otherwise stated. Test of significance for interaction was set at alpha=0.15(Stehman and Meredith, 1995)

RESULTS AND DISCUSSION

In an earlier article(Park, 1997), the growth response of willow to the fertilizer treatment and clonal differences in aboveground biomass was described. Soil chemical properties could be changed by fertilizer treatment and willow clones. However, clone effect did not appear strong at any depth for chemical properties of soil. Although some fertilization-by-clone interactions were noted for soil N, Na, and CEC(Table 1), mean separation techniques(Peterson, 1985) indicate that there were only fertilization effects for soil N, Na, and CEC. Therefore, only fertilization main effects are discussed.

Total soil N concentration(%) decreased with depth(Table 2). No significant differences were found in total soil N content(kg/ha) between fertilized and non-fertilized plots for all soil depths (Table 3). Soil C/N(Carbon/Nitrogen) ratio ranged from 9.6 to 11.2 for all soil depths and treatment combinations(Table 4). There were statistically significant and relatively strong positive correlations between soil C and N content at all soil depths except for a relatively weak correlation at the 0-10cm soil depth in the non-fertilized plots (Table 5).

Soil N content, averaged, 1,990kg/ha at 0-10 cm, 1,802kg/ha at 10-20cm, and 3,073kg/ha at 20-40cm soil depth for all treatment combinations (Table 3). Five years of fertilization added 1,680 kg/ha of N(336kg/ha/yr of N as NH_4NO_3) to the fertilized plots. Since the amount of fertilizer N present in trees after fertilization is usually less

Table 1. Analysis of variance for soil nutrient contents and CEC concentration and pH at 0-10㎝, 10-20㎝, and 20-40㎝ depth.

Soil depth	Source	df	N	P	K	Ca	Mg	Na	CEC	pH
			P-values							
0-10㎝	Fertilization	1	0.77	0.01	0.75	0.03	0.14	0.23	0.45	0.01
	Error(Fert)	4								
	Clone	5	0.39	0.62	0.08	0.83	0.63	0.60	0.99	0.46
	Clone*Fert	5	0.33	0.48	0.57	0.88	0.94	0.21	0.35	0.99
	Error	20								
	Total	35								
10-20㎝	Fertilization	1	0.86	0.01	0.01	0.04	0.22	0.14	0.12	0.06
	Error(Fert)	4								
	Clone	5	0.25	0.79	0.53	0.93	0.90	0.46	0.72	0.29
	Clone*Fert	5	0.24	0.89	0.33	0.89	0.94	0.08	0.16	0.95
	Error	20								
	Total	35								
20-40㎝	Fertilization	1	0.74	0.38	0.01	0.12	0.28	0.43	0.85	0.06
	Error(Fert)	4								
	Clone	5	0.45	0.84	0.51	0.87	0.77	0.65	0.64	0.64
	Clone*Fert	5	0.08	0.84	0.51	0.26	0.44	0.86	0.02	0.74
	Error	20								
	Total	35								

Note : Main effects are tested at alpha=0.05 and interaction is tested at alpha=0.15.

Table 2. Soil chemical properties at three soil depths in fertilized(F) and non-fertilized (NF) five willow clone and one hybrid poplar clone plots. Different letters indicate statistical difference among the three soil depths within F and NF at alpha=0.05.

Property	Treatemnt	0-10㎝	10-20㎝	20-40㎝
N(%)	F	0.19a	0.18b	0.14c
	NF	0.18a	0.19a	0.15b
P(ppm)	F	81.1a	23.1b	12.7c
	NF	16.2a	13.4a	15.4a
K(ppm)	F	132.8a	101b	78.0c
	NF	124.5a	53.5b	31.2c
Ca(ppm)	F	1,138a	1,162a	1,112a
	NF	1,637a	1,565ab	1,445b
Mg(ppm)	F	95.5a	87.8ab	79.6b
	NF	138.0a	122.7b	111.0c
Na(ppm)	F	24.8a	25.9a	29.9a
	NF	19.8b	33.4a	37.1a
pH	F	5.63b	5.78ab	5.93a
	NF	6.34a	6.31a	6.41a
CEC (cmol/kg)	F	16.2a	16.5a	14.4b
	NF	16.6a	16.0a	14.6b

Table 3. Soil nutrient contents and CEC concentrations and pH at three soil depths in fertilized(F) and non-fertilized(NF) five willow clones and one hybrid poplar clone plots. Values in the same column followed by a different letter within each depth are different at alpha=0.05.

Property	Treatment	0-10㎝	10-20㎝	20-40㎝
N(kg/ha)	F	2,023a	1,811a	3,118a
	NF	1,956a	1,793a	3,027a
P(kg/ha)	F	85.6a	23.5a	31.5a
	NF	17.0b	13.0b	6.6a
K(kg/ha)	F	138.2a	102.4a	163.1a
	NF	130.7a	52.4b	63.3b
Ca(kg/ha)	F	1,195b	1,189b	2,347a
	NF	1,716a	1,526a	2,962a
Mg(kg/ha)	F	99.9a	90.1a	168.4a
	NF	144.6a	119.6a	226.9a
Na(kg/ha)	F	26.2a	26.9a	63.9a
	NF	21.0a	32.8a	75.5a
pH	F	5.63b	5.78a	5.93a
	NF	6.34a	6.31a	6.41a
CEC (cmol/kg)	F	16.2a	16.5a	14.4a
	NF	16.6a	16.0a	14.6a

Table 4. Ratios of soil C content to content of N, P, K, Ca, Mg, and Na at three soil depths in fertilized(F) and non-fertilized(NF) five willow clones and one hybrid poplar clone plots. Values in the same column followed by different letter are different at alpha=0.05.

Ratio	Treatment	0-10cm	10-20cm	20-40cm
C/N	F	10.4b	10.4a	9.6b
	NF	11.2a	10.0a	10.2a
C/P	F	288b	875b	1,503a
	NF	1,433a	1,471a	1,077a
C/K	F	157b	197b	190b
	NF	191a	366a	504a
C/Ca	F	19.9a	16.4a	12.5a
	NF	13.6b	11.9b	10.8b
C/Mg	F	234a	229a	184a
	NF	171b	164b	154a
C/Na	F	980a	929a	542a
	NF	1,256a	727a	510a

Table 5. Correlation coefficient between soil C and soil N, P, K, Ca, Mg, Na, CEC, and pH at three soil depths in fertilized(F) and non-fertilized(NF) five willow clones and one hybrid poplar clone plots. Values in parentheses are P values

		0-10cm	10-20cm	20-40cm
C-N	F	0.88(<0.01)	0.77(<0.01)	0.78(0.01)
	NF	0.40(0.11)	0.91(<0.01)	0.95(<0.01)
C-P	F	0.54(0.02)	0.13(0.60)	0.21(0.42)
	NF	0.61(0.01)	0.49(0.04)	0.45(0.06)
C-K	F	0.34(0.17)	-0.22(0.38)	0.13(0.61)
	NF	0.66(<0.01)	0.25(0.31)	0.14(0.59)
C-Ca	F	0.56(0.02)	0.59(0.01)	0.75(<0.01)
	NF	0.81(<0.01)	0.80(<0.01)	0.84(<0.01)
C-Mg	F	0.50(0.04)	0.50(0.04)	0.51(0.03)
	NF	0.72(<0.01)	0.64(0.05)	0.72(<0.01)
C-Na	F	0.19(0.45)	0.40(0.10)	0.55(<0.01)
	NF	0.18(0.47)	0.33(0.18)	-0.23(0.36)
C-pH	F	0.20(0.43)	-0.06(0.81)	0.01(0.98)
	NF	0.25(0.32)	0.30(0.23)	0.49(0.04)
C-CEC	F	0.22(0.39)	0.47(0.05)	0.86(<0.01)
	NF	0.75(<0.01)	0.52(0.03)	0.85(<0.01)

than 30% of the applied fertilizer(Johnson, 1989 ; Heilman, 1992), as much as 70% N fertilizer could remain in fertilized plots. However, no significant differences in total N content were found between fertilized and non-fertilized plots at all soil depths for several reasons. First, total N is composed of available and unavailable N, and that the amount of available N is very small, except where large amounts of inorganic N fertilizers have been applied. Therefore, N fertilization should be thought of as fertilizing trees, but not the site, since amounts of N typically applied (100-400kg/ha) are small compared to N capital in the system in most cases(2,000-10,000kg/ha) (Miller, 1981). In the study plots, the amount of N applied annually by fertilization was 5% of the amount of nitrogen present in the upper 40cm [(fertilized N/total N)*100]. Without any loss of N from the soil, annual N fertilization for five years would increase total N concentration by 25% in the upper 40cm of the fertilized plots.

Fertilization with ammonium nitrate supplies both ammonium and nitrate ions to soil. Thus, large amounts of nitrogen in nitrate and ammonium forms may be present in fertilized soils. However, these available forms of N are easily lost from soils through leaching, plant uptake, and volatilization(Brady, 1990). Leaching loss of nitrate ions is especially high where irrigation water is applied. Since the plots used in this study were irrigated for four years, N loss by leaching could be high. Another nitrogen loss in fertilized plots could be by increased ammonia volatilization. This loss is most serious when N fertilizers are applied to the soil surface because of high soil temperature(Brady, 1990). Application of nitrogen fertilizer, to crop land, appears to substantially increase denitrification(Russell, 1961). Maintaining high soil nitrogen levels with fertilization may maximize losses from denitrification which, on crop land, can be as high as 150kg N/ha/yr(Heilman, 1992). Small dedication of fertilizer N to total N system plus N losses by leaching, volatilization, or denitrification plus plant uptake in fertilized plots could result in small differences in total N content between the two treatment plots.

In this study, soil C/N ratio ranged from 9.6 to 10.4 and 10.0 to 11.2 in fertilized and non-fertilized plots, respectively, for all three soil sampling depths(Table 4). The C/N ratio was significantly less in fertilized plots than in non-fertilized plots at 0-10cm and 20-40cm soil depths

(Table 4). This decreased C/N ratio in fertilized plots could be caused by the N addition increasing organic matter decomposition combined with the slight increase in nitrogen content. The C/N ratio of 10.0 to 11.2 in non-fertilized plots could indicate that nitrogen liberate by mineralization becomes available to higher plants.

All organic substances contain soil C. A close relationship between soil C and N is expected since organic matter is the source of nearly all N. A significant and relatively strong positive correlation between soil C content and total N content in the plots of the two fertilizer treatments at all soil depths, except 0-10cm soil depth in non-fertilizer plots, indicates the important relationship between soil C and soil N(Table 5).

Available soil P content, in the top 10cm of soil, averaged, 86 and 17kg/ha in fertilized and non-fertilized plots, respectively(Table 3). Greater P content in fertilized plots than in non-fertilized plots in the two upper soil depths were most likely from the application of 112kg P/ha/yr. Phosphorous is an immobile nutrient that does not leach and thus, unlike N, P readily accumulates in soils in inorganic forms. Turner and Lambert(1986) reported that the beneficial effect of P fertilization can last for over 30 years. A lower soil C/P ratio in fertilized plot than in non-fertilizer plot except for 20-40cm depth was found (Table 4). In the fertilized plots soil P concentration significantly decreased with depth with large differences between 0-10cm and the two lower soil depths was due to fertilization(Table 2). No differences between the various depths were found in non-fertilized plots. A significant correlation between soil C and P was observed in the upper 0-10cm of soil for both treatments and at the 10-20cm depth of the unfertilized plots (Table 5). Organic matter may provide 5 to 60% of the soil P, but the importance of the relationship between soil C and soil P has been less noticed because of the importance of the inorganic pools of soil P(Johnson, 1995). The significant corrleation between C and P in the surface horizon in the unfertilized plots indicates that organic matter is an important source of available P in the surface horizon. On the other hand, weak relationship between soil C and available P was found only at 0-10cm soil depths in fertilized plots and this would indicate that most available P in the lower horizons was from inorganic sources of P.

A total of 1,120kg/ha of K was applied to the fertilized plots during the five years before samples were collected. However, no significant difference in available soil K content was found between fertilized and non-fertilized plots at the 0-10cm soil depth(Table 3). Large amount of K can be lost by leaching from fertilized sites (Brady, 1990). Since K is a mobile element, the element could move to lower soil layers by leaching causing small differences in soil K at 0-10cm depth. Significantly greater amounts of exchangeable soil K at the two lower soil depths of the fertilized compared to the non-fertilized plots indicate leaching of the element to lower depth(Table 2). The K saturations in the two lower depths of the fertilizer plots were 1.8 to 3.1 times greater than in the non-fertilized plots while the non-fertilized plots had greater percent base saturation compared to fertilized plots(Table 6). This relationship also strongly suggests leaching of K to lower depths. Lower soil C/K ratio in fertilizer plots than in non-fertilizer plots for the all soil depths was noted(Table 4). Significant and relatively strong correlation existed between soil C content and exchangeable soil K content only at the 0-10cm soil depth in non-

Table 6. Percent saturation(%) of K, Ca, Mg, and Na at three soil depths in fertilized (F) and non-fertilized(NF) five willow clone and one hybrid poplar clone plots.

Property	Treatment	0-10cm	10-20cm	20-40cm
K(%)	F	2.10	1.57	1.39
	NF	1.92	0.86	0.45
Ca(%)	F	35.10	35.20	38.60
	NF	49.30	48.90	50.10
Mg(%)	F	4.90	4.40	4.60
	NF	6.90	6.39	6.34
Na(%)	F	0.70	0.70	0.90
	NF	0.60	0.90	1.10
B.S.(%)	F	42.82	41.87	45.49
	NF	56.82	57.05	57.99

B.S. : Base saturation

fertilized plot(Table 5). This was expected since the increase in K content in fertilized plots was the result of additions of inorganic K.

Exchangeable Ca content was significantly greater in non-fertilized plots than in fertilized plots in the two upper soil depths(Table 3). The addition of ammonium-containing fertilizers increase the release of hydrogen and nitrate ions through increased nitrification in the fertilized plots. So increased nitrate in fertilized plots can cause increased leaching of nitrate ions and associated cations. The increased nitrate and base cation leaching, as a result of N fertilization, could result in less exchangeable Ca content in fertilized plots. Also, there was a strong tendency for exchangeable Mg to be greater in non-fertilized plots than in fertilized plots for the same reasons(Table 3). There was a strong tendency for Ca and Mg saturation percentages to be greater in non-fertilization plots than in fertilized plots at all soil depths(Table 6). The result may also support leaching of the two cations in fertilized plots. Significantly positive correlation between soil C content and exchangeable Ca content was found for all soil depths in the two fertilized treatments(Table 5). The result may relate to the effects of Ca on soil C stabilization. In the case of Ca, and other polyvalent cations, cation bridging of organic colloides causes condensation and stabilization of organic matter (Oades, 1988). Significant correlations between soil C content and exchangeable soil Mg content in all plots of the two fertilizer treatments were also found at all soil sampling depths(Table 5).

Little effect of fertilization on CEC was found at all soil depths(Table 3). Organic matter contributes to the CEC, often furnishing 30-70 percent of the total number of exchange sites (Donahue et al., 1983). Significant correlation between CEC and soil C concentration at all soil depths in non-fertilized plots and at 20-40cm depth in fertilized plots could indicate the contribution of organic matter to CEC(Table 5). However, significant correlation between soil C and CEC was not found at all soil depths and the result may indicate contribution of soil texture to CEC. Most of the soil's CEC occurs on clays and soil humus(Donahue et al., 1983).

Soil pH ranged from 5.6 to 6.4 in three soil depths for all treatment combinations(Table 3). Soil pH was significantly greater in non-fertilized than in fertilized plots at the 0-10cm soil depth. This is probably due to acid formation by ammonium-containing fertilizers. Addition of ammonium-containing fertilizers increases the process of nitrification, and thereby increasing the release of nitrate and hydrogen ions. Increased hydrogen ions on the soil colloides could result in increased soil acidity in fertilized plots. Also, as described earlier, fertilizer N could cause increased nitrate and base cation leaching (Ca^{2+} and Mg^{2+}) and so increase acidity. Since increases in the base cation percentage indicate the tendency toward neutrality and alkalinity (Brady, 1990), greater percent base saturation in non-fertilized plots compared to fertilized plots also support the result of lower soil pH in fertilized plots than in non-fertilized plots(Table 6). Increased soil pH with depth in fertilized plots was found(Table 2) and the result could also be from increased hydrogen ions at 0-10cm soil depth plus leaching of nitrate and base cations to lower depth. There was no strong correlation between soil C concentration and pH(Table 5).

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