NITRATE AND PHOSPHATE DISTRIBUTION IN SOIL AND RUNOFF WATER UNDER DIFFERENT MANAGEMENT SYSTEMS ON AN ALFISOL IN SOUTH-WESTERN NIGERIA

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Abstract

The rate and intensity of inorganic fertilizer usage has increased in recent years in Nigeria, in response to increasing demand for food. There is currently no particular regulation on inorganic fertilizer usage in Nigeria and no efforts are being made to restrict its overuse in order to avoid risk of soil and surface water contamination. This study was therefore carried out to determine the impact of agricultural land management on the distribution of NO_3-N and PO_4-P in soil and runoff water. The study was done in Ibadan Nigeria, on a ten hectare (ha) experimental farm that had been subjected to long term cultivation with and without inorganic fertilizer application. Four sites, each about 2 ha under different land management were identified. They are (i) continuous cultivation with high fertilizer application at high dosage (CTHF), (ii) continuous cultivation with intermittent fertilizer application at low dosage (CTLF), (iii) continuous cultivation with no fertilizer application (CTNF) and (iv) a regenerated forest (FR). Replicate soil samples collected at depths of 0-15, 15-30, 30-100 and 100-180 cm from different landscape positions under each treatment along with surface runoff water, were collected and analysed for their physical and chemical properties. Bulk density of the surface (0-15 cm) soil was highest under FR (1.59 mg m^{-3}), however among the cultivated treatments, it increased with increased intensity of land use and was least under CTNF (1.42 mg m^{-3}). Soil pH was highest under FR (6.17) and least under CTHF (5.22). Both surface soil NO_3-N and PO_4-P were highest under FR (8 mgkg^{-1}) but increased with increased inorganic fertilizer usage from 3.5 mg kg^{-1} under CTNF to about 5 mg kg^{-1} under CTHF. However, while the soil NO_3-N content decreased down the profile under FR (from 14 mgkg^{-1} at surface level to 6 mgkg^{-1} at 100-180 cm depth) it increased down the profile under CTHF (from 3 mgkg^{-1} at surface level to 5.5 at 100-180 cm depth). The concentration of NO_3-N and PO_4-P in surface runoff water was highest under CTHF and least under CTNF. Landscape position however had no significant effect on the soil distribution of NO_3-N and PO_4-P.

Keywords: Alfisol, southwestern Nigeria, bulk density, runoff, fertilizer use, land management.

Introduction

Phosphorous and nitrogen are essential elements for plant growth. However, when not properly managed their losses from soil may impact negatively on the quality of surface water bodies and underground sources of water and pose health hazards. The highly weathered tropical soils of Nigeria are known to be poor in native phosphorous. Moreover, a large part of these are occluded by sesquioxides present in soil, making them practically unavailable for plant nutrition. Fractions of P applied as inorganic fertilizers are also often adsorbed by oxides of Fe and Al that are present in the soil. This often results in poor response by crops to added P fertilizers. To ensure crop response, there is often indiscriminate use of large quantities of inorganic P fertilizers to supplement P in these oxide rich soils. This has in recent times increased the P supply to crops and also heightened the risk of nutrient loss relative to unfertilised land. Intensification of agriculture based on high inputs of fertilizers and pesticides is however inevitable in Nigeria because of the rapidly increasing population (Lal 1997). Arable land in Nigeria currently receives N and P fertilizers in excess of 130 and 50 $kgha^{-1}$ respectively (Agbenin and Goladi 1997).

Losses of nitrogen and phosphorous from agricultural and forestry land to down-stream, results in water contamination with serious consequence on living components in an aquatic environment (Hodgkin and Hamilton 1993). The potential for algae to bloom is governed to a large extent by the supply of N and P concentrations, and eutrophication may occur if the total P concentration in water is greater than 0.5 and 0.1mg/L. (Anon 1992; Foy and Wither 1993; Sharpley 1995). Loss of fertilizer NO_3-N and PO_4 from the crop-soil system represent both an economic loss to farmer and environmental hazards. Quality of surface water is of special importance in Nigeria because most rural population depend on surface water for domestic needs often without further treatment. While soluble nutrients such as nitrates may be transported in the solution phase, the less soluble ones such as phosphates are usually entrained with eroded sediments (Lal 1976). This tends to adversely affect water quality from agricultural lands. This study is therefore aimed at investigating PO_4-P and NO_3-N distribution in profiles of soils subjected to various levels of fertilizer management. It has the ultimate objective of determining the potential impact of land management and the use of inorganic fertilizers on P and N concentration in runoff water in a sandy clay loam soil in southwestern Nigeria.

Materials and methods

The study area

The study area is located within the experimental farm of the Institute of Agricultural Research and Training (IAR&T) of Obafemi Awolowo University, located in Ibadan, Nigeria. Ibadan lies within latitude 7º 6' E to 7º 7' E and longitude 3º 50' N and 3º 51' N. The climate is humid tropical with bimodal rainfall extending from March to October. The average annual rainfall in Ibadan is about 1230 mm with annual average temperature of 27ºC (FAO, 1993). The soil, which is classified as Oxic Paleustalf (Ojo-Atere *et al.* 1990), is derived from gneiss and schist parent materials.

The farm, which is approximately 10 ha in size, was classified based on its past land management and fertilizer use histories into four classes of about 2.5 ha each. (i) farmland under continuous cultivation with continuous use of fertilizer applied at optimum rate designated as continuous cultivation with high fertilizer level (CTHF), (ii) farmland under continuous cultivation with intermittent use of fertilizer often below the optimum rate designated as continuous cultivation with low fertilizer usage (CTLF), (iii) farms with continuous cultivation with no fertilizer usage (CTNF), and (iv) a regenerated forest (FR). Data on the exact rate of previous fertilizer application on cultivated farm plots were not available. Each of the farmlands had been subjected to at least 10 years of continuous cultivation with maize, while the regenerated forest had been under undisturbed fallow for not less than 20 years. Each of these sites was sub-divided according to landscape positions into top, middle and lower landscape positions. The cultivated plots had been continuously cultivated with maize crops only for all the cropping durations. At sampling time, all the plots with the exception of the FR, had just been cultivated to maize. Fertilizer (NPK 15:15:15) were applied on the fertilized plots on May 20, 2001 and soil sampling was done about a month after (June 18 – June 24, 2001).

Sampling procedure
Soil samples were collected for laboratory analyses at depths of 0–15, 15 – 30, 30 – 100 and 100 – 180 cm at each landscape positions, in order to establish the vertical distribution of P and N in the soil. Samples were collected with a stainless steel Dutch auger. Three replicate samples were collected from each plot. Steel cores of diameter 13 cm and 15 cm height were used to collect undisturbed samples for bulk density determination. Soil bulk density was calculated after oven-drying as the mass of soil particles over the core volume after correcting for gravel content, because of the gravelly nature of the soil.

Mini runoff collection troughs were installed on the different landscape positions (about 0.01 ha per site) across the land management types to collect runoff water and sediments. Runoff collection was done for four successive rainfalls spanning June 19 to June 24, 2001. The runoff water and sediments were analyzed for NO_3-N and PO_4-P contents.

Laboratory analyses
Soil pH was determined in 0.01M $CaCl_2$, while soil organic carbon content was determined by chromic acid oxidation Method (Walkley and Black 1934). Exchangeable cations were extracted with normal, neutral ammonium acetate solution; and the Ca and Mg contents of the extract were determined with atomic absorption spectrophotometer. Soil exchangeable acidity was determined by barium chloride-triethanolamine extraction method (Mehlich 1948). Nitrate in the soil extract was determined in a Technicon AA11 autoanalyser (Technicon Instruments Corp. 1973), method, while available phosphorus was determined by a modified Bray 1, (Bray and Kurtz 1965). Particle size analysis was determined by hydrometer method (Bouyoucos 1951) after dispersing the soil suspension with sodium hexametaphosphate (Calgon). Phosphate and nitrate in the runoff were determined using standard method described by APHA (1995).

Results and discussion

Soil properties
The means of the physical properties of the soil are shown in Table 1. The soil was slightly acidic with pH increasing from 5.46 within the top 0-15 cm of the soil to 5.51 at the 100-180 cm soil depth. The sand content of the soil decreased down the profile while clay increased down the profile. The soil is generally gravelly with gravel contents as high as 62% between 100-180 cm soil depth. The soil's PO_4-P, exchangeable acidity, exchangeable Ca and Mg, and organic carbon all decreased down the profile, while NO_3-N distribution in the soil profile showed no definite pattern (Table 2).

Table 1. Mean (across all landuse types and landscape classes) of profile distribution of soil physical properties in the an alfisol in Ibadan, Nigeria. (Values in columns followed by the same letter are not significantly different at p=0.05 according to Duncan's Multiple Range Test)

Soil depth (cm)	Bulk density (mg m^{-3})	pH ($CaCl_2$)	Sand	Silt	Clay	Gravel
			←		(%)	→
0-15	1.48	5.46	69.54a	11.74a	18.74b	51.61bc
15-30	nd	5.46	69.48a	9.25a	23.60b	48.94c
30-100	1.56	5.46	47.87b	9.53a	43.31a	58.11ab
100-180	nd	5.51	39.51c	10.19a	46.44a	61.75a

nd = Not determined

Table 2. Mean (across all land management types and landscape classes) of profile distribution of soil chemical properties in an alfisol in Ibadan, Nigeria. (Data in columns followed by the same letter are not significantly different at p=0.05 according to Duncan Multiple Range Test)

Soil depth (cm)	NO_3-N (mg/kg)	PO_4-P (mg/kg)	Ex. Acidity	Exch. Ca	Exch. Mg	Organic carbon
			←	(cmol/kg)	→	(g/kg)
0-15	4.28a	4.94a	1.15a	8.12a	1.57a	9.80a
15-30	4.08a	1.18b	0.93a	3.27b	1.18b	7.10b
30-100	3.04b	0.47c	0.69a	2.75d	0.73b	5.20c
100-180	4.21a	0.76c	0.81a	2.24c	1.00b	3.70d
Std. error	0.76	0.25	0.08	0.51	0.23	0.64

Effects of landuse types

Table 3 shows the response of soil bulk density to the different land use systems. The surface (0-15 cm) soil bulk density was highest (1.59 mg m^{-3}) under FR and lowest under CTNF (1.42 mg m^{-3}) when averaged across the landscape positions. However, the bulk density of the surface soil under CTNF was significantly lower (P = 0.05) than under both

CTHF and the CTLF plots, while there was no significant difference between CTHF and CTLF. The significantly lower bulk density (P = 0.05) of the cultivated plots compared to the forested plot (FR) may be as a result of loosening effect of tillage operations during cultivation. Unger and Jones, (1998) and Franzluebbers *et al.*, (1995) similarly recorded lower soil bulk density of surface 0-10 cm soil under continuously cultivated plots compared with no-tillage plots. The sub-surface (30-100 cm) soil bulk density was significantly higher than the surface (0-15 cm) for all the cultivated landuse types. There was however no significant difference in the sub-surface (30-100 cm) soil bulk density among the different land management types.

Table 3. Response of soil bulk density (mg m^{-3}) to the land management (fertilizer) types

Soil depth (cm)	**Land use type**				**Statistics**	
	CTHF	**CTLF**	**CTNF**	**FR**	**SE ±**	**LSD**
0-15	1.48	1.47	1.42	1.59	0.01	0.04
15-30	nd	nd	nd	Nd		
30-100	1.59	1.55	1.52	1.51	0.03	0.11
100-180	ND	ND	ND	ND		
Std. error	0.01	0.02	0.04	0.02		
LSD	0.03	0.05	0.13	0.06		

CTHF = Cultivation with high rate of fertilizer application
CTLF = Cultivation with low rate of fertilizer application
CTNF = Cultivation with no fertilizer applied
FR = Regenerated forest
nd = Not determined

Table 4. Response of soil pH to the land management (fertilizer) types

Soil depth (cm)	**Land use type**				**Statistics**	
	CTHF	CTLF	CTNF	FR	Std. error	LSD
0-15	5.22	5.33	5.70	6.17	0.18	0.50
15-30	5.28	5.32	5.63	6.10	0.14	0.40
30-100	5.17	5.33	5.60	6.13	0.11	0.32
100-180	5.00	5.40	5.63	6.10	0.11	0.33
Std. error	0.17	0.06	0.05	0.07		
LSD	0.50	0.17	0.19	0.26		

CTHF = Cultivation with high rate of fertilizer application;
CTLF = Cultivation with low rate of fertilizer application;
CTNF = Cultivation with no fertilizer applied;
FR = Regenerated forest.

Soil pH generally decreased down the profile under all land management types (Table 4). This may be due in part to the high rainfall in the area. The heavy rainfall causes excessive leaching of basic cations from the exchange sites and the substitution of these by hydrogen ions and this depresses the soil pH. Significant differences in soil pH were observed among the different landuse types. The soil under FR was significantly less acidic (pH = 6.17) compared to the continuously cultivated plots. The soil pH dropped significantly by a unit of 0.95 in FR compared with CTHF plot, meanwhile the difference between the FR plots and the CTNF plots was not statistically significant at the surface (0-15 cm) soil. The soil under CTHF was significantly more acidic than other plots. Increased acidity with continuous cultivation has been reported on soils of the tropics (Aina 1979; Jaiyeoba 2003). This can be attributed to a combination of the effects of soil nutrient removal with harvested crops and the leaching of exchangeable cations caused by the prevalent heavy rainfall conditions. The bio-cycling of organic matter and nutrients ensure the replenishment of removed nutrients under forest.

The effects of landuse type on soil NO_3-N and PO_4-P is shown in Fig 1. The soil PO_4-P is concentrated on the top soil layer decreasing sharply down the profile. This was the case across all land management types. The FR soil however accumulated the highest amount of PO_4-P in the top 0-15 cm soil layer followed by CTHF land management type. The value was lowest for the plot with no fertilizer usage (CTNF). This may indicate that the soil P level is still below saturation. Meanwhile, the soil nitrate decreased down the profile across all the land management types with the exception of the CTHF plots where it significantly increased down the profile (Fig 1). The forest soil also had the highest concentration of NO_3-N, at all depths sampled. There was however no significant differences in CTHF and FR treatments at about 180 cm of soil depth. At a depth of 180 cm, the soil NO_3-N content under CTHF management (5.8 $mgkg^{-1}$) was almost twice the value under CTNF (2.8 $mgkg^{-1}$). The clayey nature of the subsoil may limit the soil permeability at this depth thus favouring NO_3-N retention at lower depths. This may explain the slight increase in soil content of NO_3-N at a depth of 100-180 cm across all land management types. The soils rich in organic matter under the forest and the humid tropical environment provide an enabling environment for quick mineralisation of organic matter and the production of NO_3-N rich soil. The fairly significantly high soil profile distribution of NO_3-N is an indication of leaching of applied N and point to the capacity of agricultural land use to negatively impact the NO_3-N concentration of ground water.

Effects of landscape position

Figure 2 shows the distribution of soil pH, NO_3-N and PO_4-P under the different landscape classes. There was no consistency in the distribution of pH throughout the profile under the different landscape positions. For example, pH generally decreased down the profile for lower and upper landscape positions while the reverse was the case in the middle landscape position. Soil pH was however lowest on the upper landscape and highest in the middle landscape position. This is consistent with the findings of Zebarth *et al.*, (2002) that reported no consistent relationship between soil pH distribution and landscape position.

The soil NO_3-N content was fairly uniform on all sampled depths at the lower landscape position. It decreased with depth at the middle landscape position and increased with increasing depth at the upperslope position. The midslope position also had the highest concentration of soil NO_3-N. This was however not consistent with findings of Boerner and LeBlanc, (1995) who observed a significantly higher soil cocentration of NO_3-N in the lower landscape position.

Soil PO_4-P was concentrated more on the surface 0-15 cm soil in the three landscape positions with the midslope position also recording the highest PO_4-P distribution while there was no significant difference observed among the different landscape positions at lower soil depth. Zebarth *et al.*, (2002) similarly observed no difference in soil distribution of P among different landscape positions

NO_3-N and PO_4-P in runoff

The PO_4-P concentrations of the runoff water under CTHF land management practice was highest (34.6 mg L^{-1}) followed by CTLF (19.8 mg L^{-1}), while it was least under CTNF (7.5 mg L^{-1}). There was no significant difference between CTNF and FR management practices (Fig. 3). The high PO_4-P load of runoff water is associated with applied P fertilizers which are apparently transported with soil particles detached from soil surface during erosion process. However the NO_3-N content of runoff water differ significantly among the different land management practices. The highest concentration was also recorded under the CTHF management practice. The average volume of runoff water from the cultivated plots at the time of sampling was about 400 L/ha for each rainfall. The NO_3-N concentration of about 15 mg/L in runoff under the CTHF plots translates to about 0.6 kg ha^{-1} of NO_3-N being added to the water bodies in the catchment. This would be higher immediately after fertilizer application, a period when the surface cover is still sparse and erosion is at maximum. The continuous addition of this load of NO_3-N and PO_4-P with runoff water from agricultural land may negatively impact the surface water resources of the area.

The effects of landscape position on runoff load of NO_3-N and PO_4-P is presented in Fig 4. The lower landscape position had the highest concentration of both N (17.6 mg L^{-1}) and P (39.6 mg L^{-1}). The lower slope represents the deposition zone where the concentration of ions in runoff water is expected to be high. The least concentration of P and N in runoff was recorded in the middle landscape position

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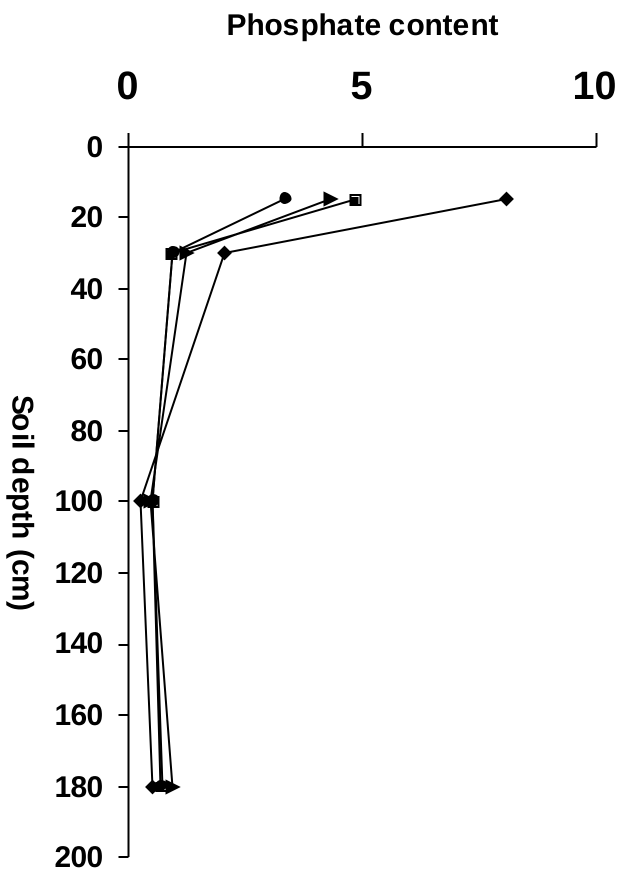
Fig 1: Effects of management options on (a) PO_4-P and (b) NO_4-N (mg kg^{-1})distribution in sol with depths of sampling in an alfisol in Ibadan, Nigeria.. CTHF = Cultivation with high rate of fertilizer application; CTLF = cultivation with low rate of fertilizer application; CTNF = cultivation with no fertilizer applied; FR = regenerated forest

Fig. 2: Soil profile distribution of (a) pH, (b) PO_4-P and (b) NO_3-N (mg kg^{-1}) in different landscape positions on an alfisol in Ibadan, Nigeria.

Fig 3: Effect of farm management options on NO_3-N and PO_4-P (mg L^{-1}) load of runoff water in an alfisol in Ibadan, Nigeria. CTHF = Cultivation with high rate of fertilizer application; CTLF = cultivation with low rate of fertilizer application; CTNF = cultivation with no fertilizer applied; FR = regenerated forest. Bars with the same alphabets are not significantly different at P = 5% according to Duncan's Multiple Range Test

Fig. 4: Effect of landscape position on the NO_3-N and PO_4-P (mg L^{-1}) load of the runoff water on an alfisol in Ibadan, Nigeria. Bars with the same alphabets are not significantly different at P = 5% according to Duncan's Multiple Range Test.

a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5
10
Soil depth (cm)
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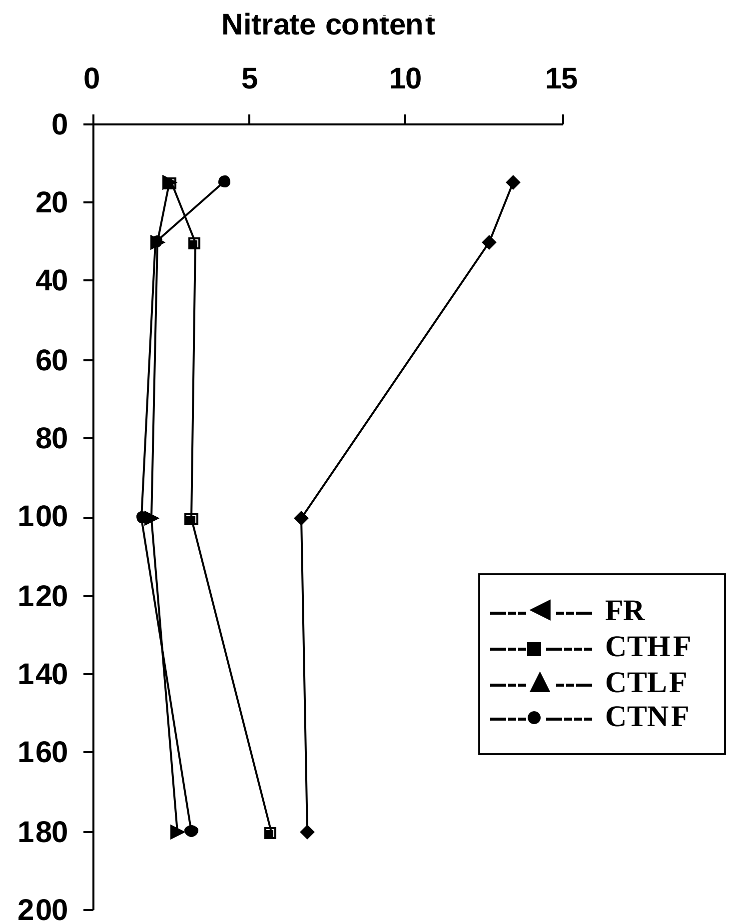
20
40
60
80
100
120
140
160
180
200

b


Nitrate content
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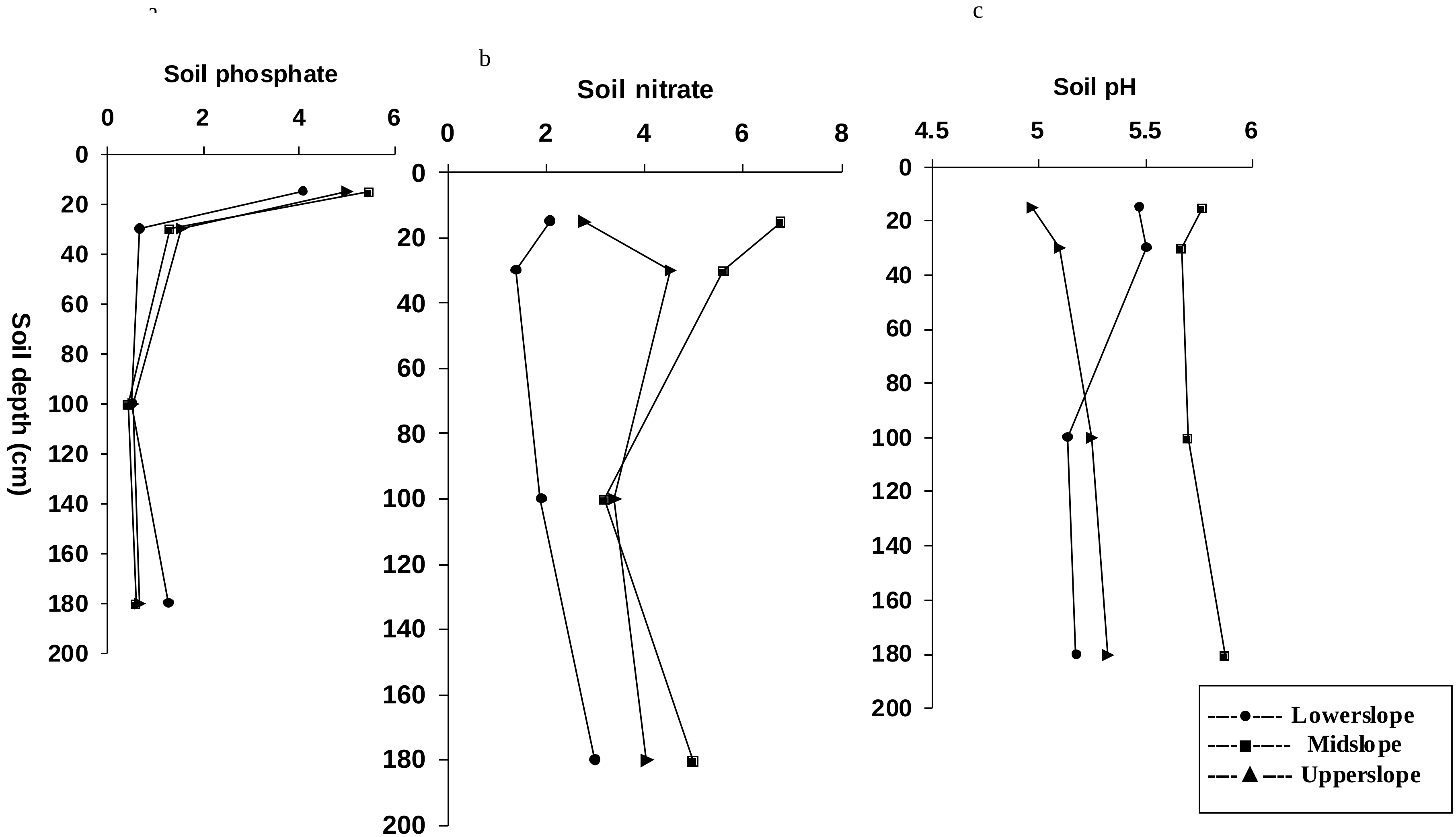
0
20
40
60
80
100
120
140
160
180
200
FR
CTHF
CTLF
CTNF


a
Soil phosphate
0 2 4 6
0 20 40 60 80 100 120 140 160 180 200
Soil depth (cm)
b
Soil nitrate
0 2 4 6 8
0 20 40 60 80 100 120 140 160 180 200
c
Soil pH
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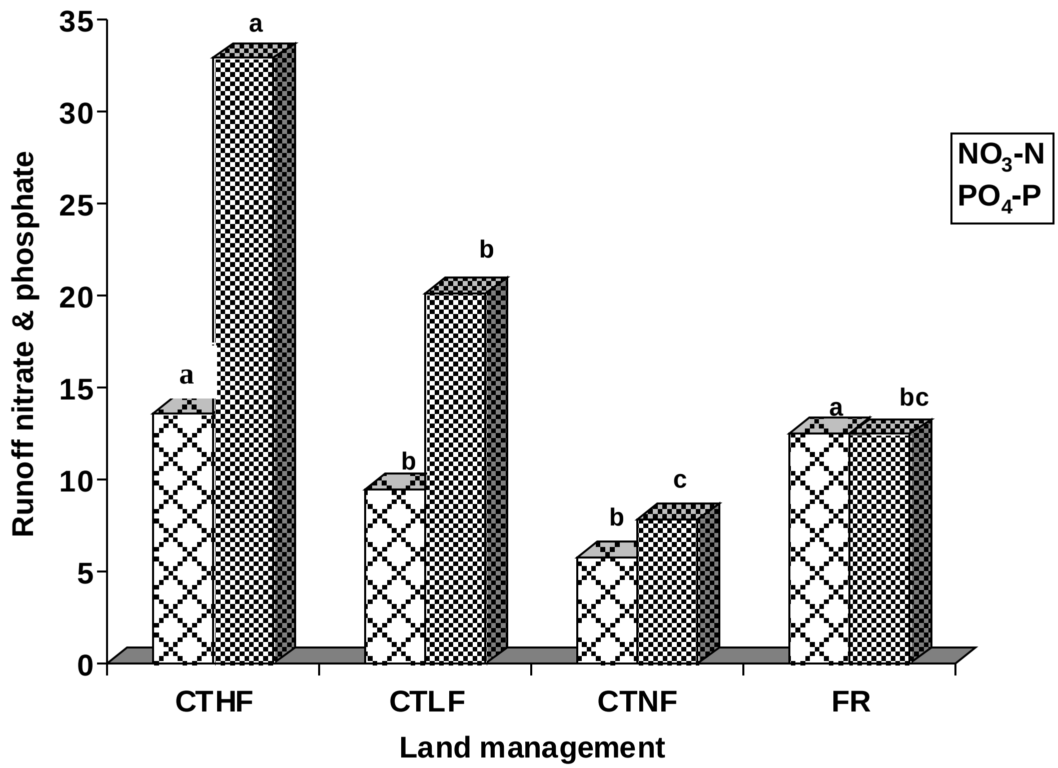
0 20 40 60 80 100 120 140 160 180 200
Lowerslope
Midslope
Upperslope


35
30
25
20
15
10
5
0
Runoff nitrate & phosphate
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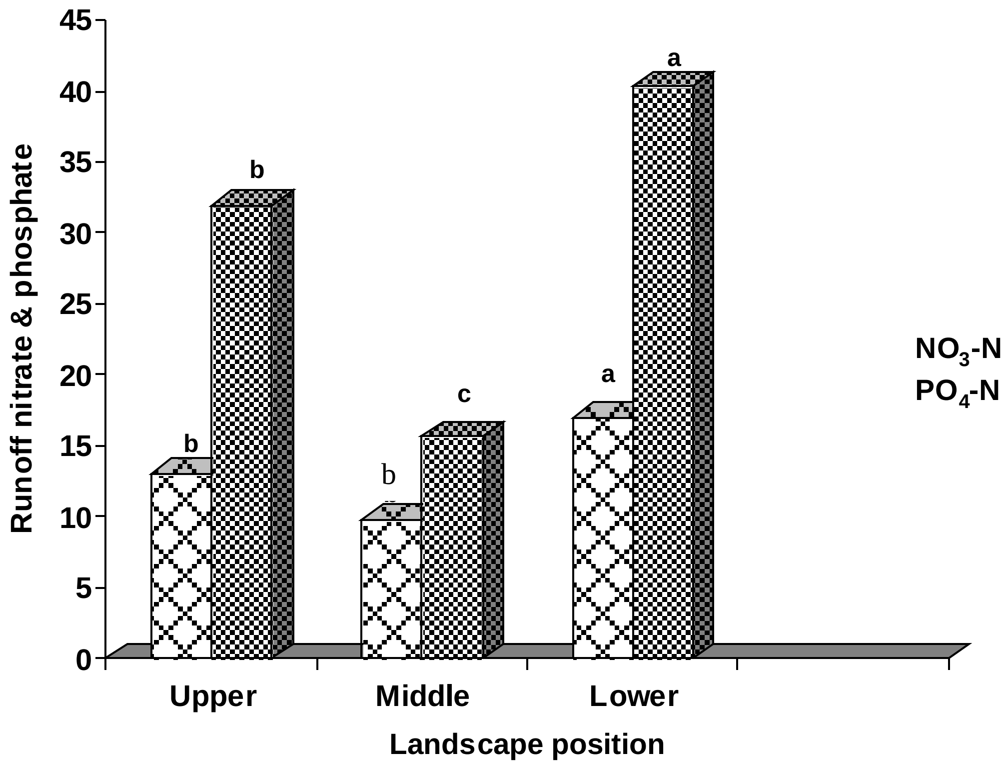
a
b
b
b
c
a
bc
NO3-N
PO4-P
CTHF
CTLF
CTNF
FR
Land management

.


45
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35
30
25
20
15
10
5
0
Runoff nitrate & phosphate
a
b
c
a
b
b
Upper
Middle
Lower
Landscape position
NO3-N
PO4-N