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Distribution of nitrate and related nutrient stocks in a fertilised horticultural valley soil in central Uganda

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ABSTRACT
The drive to modernise agriculture in Uganda is generally resulting in increased utilisation of agrochemicals, including fertilisers. Unregulated use of many chemicals is widely believed to be a threat to agroecologies and, consequently, to human livelihoods. Unfortunately, use of agrochemicals is inevitable especially in light of the increasingly dwindling natural resource base, and the ensuing plant physiological stresses. A study was conducted at the Makerere University Agricultural Research Institute, Kabanyolo in central Uganda, to evaluate a horticultural soil for the distribution of nitrate ion species and other important soil properties within soil profiles, relative to the water table. Soil samples were taken from four representative sub-sites (as replicates) within a valley, at depths of 0-20, 20-40, 40-60, 60-80 and 80-100 cm. The entire profile depth was strongly acidic, with pH values <4.5. Vertical nitrate movement within the profile was phenomenal and caused a bulge in the lower depths of the soil profile. Soil organic matter and total N followed suit, suggesting a reasonable intensity of drainage within this valley soil. The water table was as high as 80 cm profile level, hence, the potential for nitrate loading into groundwater is high.

Key words: Environment pollution, horticulture, nitrate ion, water table

RÈSUMÈ
La volonté de moderniser l'agriculture en Ouganda se traduit généralement par une utilisation accrue des produits agrochimiques, y compris les engrais. L'utilisation non réglementée de nombreux produits chimiques est largement considérée comme une menace pour les agroécologies et, par conséquent, pour les moyens de subsistance humains. Malheureusement, l'utilisation de produits agrochimiques est inévitable, surtout à la lumière de la diminution croissante des ressources naturelles et des stress physiologiques des plantes qui en résultent. Une étude a été menée à l'Institut de recherche agricole de l'Université Makerere, à Kabanyolo, dans le centre de l'Ouganda, pour évaluer un sol horticole pour la distribution des espèces d'ions nitrate et d'autres propriétés importantes du sol dans les profils de sol, par rapport à la nappe phréatique. Des échantillons de sol ont été prélevés sur quatre sous-sites représentatifs (sous forme de répliques) dans une vallée, à des profondeurs de 0-20, 20-40, 40-60, 60-80 et 80-100 cm. La profondeur totale du profil était fortement acide, avec des valeurs de pH <4,5. Le mouvement vertical des nitrates dans le profil était phénoménal et a provoqué un renflement dans les basses profondeurs du profil du sol. La matière organique du sol et l'azote total ont emboîté le pas, suggérant une intensité raisonnable de drainage dans le sol de cette vallée. La nappe phréatique était aussi haute que le niveau de profil de 80 cm, par conséquent, le potentiel de chargement de nitrate dans les eaux souterraines est élevé.

Mots clés: Pollution de l'environnement, horticulture, ion nitrate, nappe phréatique

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INTRODUCTION

Economic and environmental problems associated with high agricultural chemical inputs use are prone to occur in both developing and developed countries. Edwards *et al*. (1990) noted that food production increased dramatically through the Green Revolution primarily based on high yielding varieties of crops that responded to high fertilisers inputs. Fertiliser use has increased nearly 10-folds since World War II. Current application rates are staggering and greatly exceed the amounts absorbed by plants (FAO, 2017).

Uganda is heavily dependent on agriculture, among all the production sectors of the economy. Up to 80% of the Ugandan population is engaged in this sector at production level, and even more if agro-processing is considered (Edson, 1994). Despite the importance of this sector to the country, it is still the small-scale farmers who constitute the backbone at production level (MFPED, 2001). These are typically low-input farmers who depend largely on field expansion rather than intensification (increased production per unit area). This is all due to many historical factors, the main one being traditional peasantry, lack of reliable markets, price controls (previously), general lack of entrepreneurship and more primarily, inadequate extension services.

With the recent market liberalisation policies and drive towards agricultural modernisation, the perception of agriculture as subsistence activity is rapidly changing. Agriculture is increasingly being undertaken as a business enterprise and more and more medium to large scale farms have sprung up. Use of agricultural inputs, especially agrochemicals (i.e. fertilisers and pesticides) is equally on the rise (Turyatunga, 1995). Other locally available inputs on-farms, with a potential to cause environmental pollution, such as animal manure, are also increasingly being applied. The utilisation of these inputs, though desirable, needs to be monitored to forestall possible negative effects on other environmental sectors.

Among the major known agricultural pollutants is the nitrate form of nitrogen. Nitrate is a highly mobile ion species in the soil (Singh and Kanehiro, 1969; Ascott *et al.,* 2017), and often ends up in the ground and surface water resources through leaching and surface run-off, respectively. The geochemical fate of excess nitrate is complex, but it is evident that much of it becomes non-point source pollution that degrades both surface waters and valuable groundwater supplies. Hence, uncontrolled use of nitrate fertilisers, both organic and inorganic, almost invariably results in nitrate loading in various water bodies. Unfortunately, high nitrate concentration in domestic water is known to be hazardous to both humans and livestock. In blood, nitrate competes with oxygen for hemoglobin and, therefore, impairs oxygen transport and availability in the body (Addiscott *et al.,* 1992). Consequently, defects known as met-hemolobinemia or blue baby syndrome ensue (Bockman and Bryson, 1989; Yang *et al.,* 2007). Other maladies include gastric cancer, high blood pressure and heart failure (Comly, 1945; Yang *et al.,* 2007). As such, the World Health Organisation (WHO) recommends the minimum acceptable NO_{-3} concentration in drinking water to be 20 mg l^{-1}.

In other sectors of the environment, high nitrate concentration in the soil results in the destruction of the ozone layer, caused by nitrous oxide after nitrate reduction (Parson, 1993); and eutrophiction of lakes, rivers and ponds (Wasswa, 1997; Ascott *et al.,* 2017). Therefore, nitrate level monitoring is essential to avert such catastrophic occurrences. Dismal efforts have been directed at tracking nitrate movements in Sub-Saharan Africa, and virtually none in the Uganda's growing horticultural industry with geometric-fold rises in fertiliser use. This study, therefore, was designed to assess the level of nitrate and extent of its mobility in a valley soil, applied with mineral fertilisers and cattle manure, for horticultural production in Uganda.

MATERIALS AND METHODS

This study was carried out at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK), located in central Uganda. Specifically, MUARIK is located at 0º 28'N, 32º 38' E and altitude of 1200 metres above sea level. It experiences a bimodal rainfall pattern, with an annual mean of 1500 mm. Mean annual temperature is 23.9 ºC. Horticulture is mostly practiced in the valleys in order to take advantage of the delayed onset of the drought effect in that ecology.

The study site was Kyetume valley, where most of MUARIK's horticultural activities were based. The main horticultural crops grown there included yams (*Dioscorea* spp) and cabbage (*Brassica oleraceae*). Other crops grown in the area included sugarcane (*Saccharum* cvs) and pineapples (*Ananas comosus*). Fields were variously applied with organic and inorganic fertilisers, on a seasonal basis, with great emphasis on N, P and K. Physiographically, valley slopes were in the range of 15-20% and these abruptly phased into narrow and flat bottom lands. The overall catchment is characterised by the Buganda Catena, that is, broad rounded ridges sloping into swamps which eventually drain northwards into the Nile river basin system (Mwebaza and Jimmy, 1974).

The soils in the valley are water-logged, resulting into reduction of iron and other related metal oxides; hence the appearance of mottle variegations within the subsoil. Clay is also heavily stained with humus (Mwebaza and Jimmy, 1975).

Within the study valley, four sub-sites were randomly selected on the basis of history of manure or fertiliser application (Figure 1). The sub-sites had cabbage growing on them.

From each of the sub-sites, soil samples were randomly collected from four spots, by augering at five depths, 0-20, 20-40, 40-60, 60-80 and 80-100 cm. Samples from each site were treated independently. Moist portions of the samples (approximately 200 g) were taken and refrigerated at 4 ºC prior to nitrate-N determination. The rest of the samples were

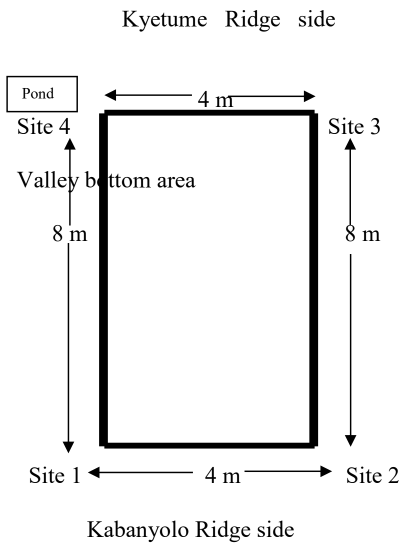

Figure 1. Diagrammatic representation of the study plan

subjected to analysis for pH, organic matter content, and total N and nitrate concentrations. All parameters were analysed using procedures described by Okalebo *et al*. (2002). Data collected were subjected to GenStat software for analysis of variance; while significant means were separated using Fishers Protected Least Significant Difference at 5% probability level.

RESULTS AND DISCUSSION

Sub-site soil profiles presented no significant differences ($p>0.05$) in soil properties evaluated, hence, only pooled data for the valley are presented (Table 1).

Soil pH. Soil pH values were strongly acidic and were much lower than Okalebo *et al*. (2002) prescribed limit for agronomic purposes. The acidification trend increased down the profile depth, implying evidence of leaching of acid or acid causing ion species such as aluminium (Al3+) and iron (Fe2+). Acidification could also be a consequence of continuous use of acid forming fertilisers, most commonly the amminiacal based mineral fertiilisers. For viable crop production on this site, there is need for integration of a liming regime to restore the desired pH values. Kitchen ash, which has no immediate alternative use in households in Uganda, could be used for this purpose, as commercial liming materials tend to be costly to most small scale farmers. Production of acid tolerant horticultural crops is also recommended.

Soil organic matter and total nitrogen. The trends for soil organic matter and total N were similar to that of pH along the soil profile depth, that is, increasing depth-wise (Table 1). This was quite surprising in light of previous reports which suggest high accumulations in the top horizons relative to deep horizons due to the natural input mechanisms which are earth surface based (Gandhiv, 2019). For N, the immediate explanation would be that the nutrient is present largely in mineral form which is prone to leaching under good drainage conditions. Nevertheless, the relative values of nitrate-N and total N present the contradictory view. There is need for further studies to elucidate the different pools of N in the site soil horizons and expose the cause of the contrasting values of soil organic matter and total N in the profiles. Otherwise, the concentration of these resources in those deep horizons will not only endanger the quality of subsurface water systems, but also deny most shallow rooted annual crops of those resources.

Nitrate nitrogen. Nitrate concentrations similarly increased dramatically in the subsoil

Table 1. Pooled site data for nitrate-N and selected soil properties of a profile in the Kyetume valley of Makerere University Agricultural Research Institute, Kabanyolo in central Uganda

Soil profile horizon (cm)	pH (water)	OM (%)	Total N (%)	NO_{-3} (mg kg^{-1})
0-20	4.55	4.86	0.277	5.4
20-40	4.35	6.50	0.375	4.2
40-60	4.10	9.39	0.530	10.1
60-80	3.75	9.82	0.570	10.7
80-100	3.65	11.86	0.692	19.2
Critical values	5.5[a]	3.0[a]	0.2[a]	20.0[b]

Source of critical values: [a]Okalebo *et al*. (2002); [b]Comyl (1945) beyond the 40 cm depth mark, and climaxed within the 80-100 cm horizon. The concentration in this depth range nearly quadrupled that of the 0-40 cm depth range. Although the nitrate concentrations in most horizons in the soil profile were less than the WHO recommended concentration minimum (Comyl, 1945), nitrate build up within the deep sub-soil horizons is evident and raises concern particularly as it occurs in a valley which is part of the catchment from which a stream that dissects the valley sources its water. This stream's water is widely used by communities of the neighbourhood for human and livestock consumption. In fact, the 80-100 cm depth nearly hit the critical limit. It is important to note that nitrate data in this study were expressed on soil basis and not on solution basis in the context of the World Health Organisation. It is, therefore, possible that the latter could possess higher nitrate concentrations than was portrayed to be in this study. It is imperative, therefore, that further studies are done to evaluate the actual water resources in the area in order to provide a complete picture of nitrate within the environments. This study, however, has provided a valuable clue of the trend most of which is a precursor for nitrate loading in the environment and water systems in particular.

A contrasting argument could be advanced if the drainage of the valley soils is found to be poor, hence, impairing the swift mobility of nitrate into sub-surface water bodies. This argument, however, may not hold true in light of the clear and direct multiple-fold build up of nitrate in the sub and deep horizons. Nevertheless, it is prudent that studies are done to clarify on the vertical and horizontal drainage systems, as they relate with nitrate movement in the valley soil.

The most plausible fix for the small scale farmers who dominate vegetable growing in Uganda, is the use of deep rooting crops to intercept and recycle the deeply leached nitrate back into the agricultural soil layers. This is most feasible under the fallow systems, which might be currently non-practical in light of the growing land size limitations. Nevertheless, integration of agroforestry tree/shrub species with multiple uses could offer a window of opportunity for obviating the concerns and yet bolster the use efficiency of the nutrient resources in the country.

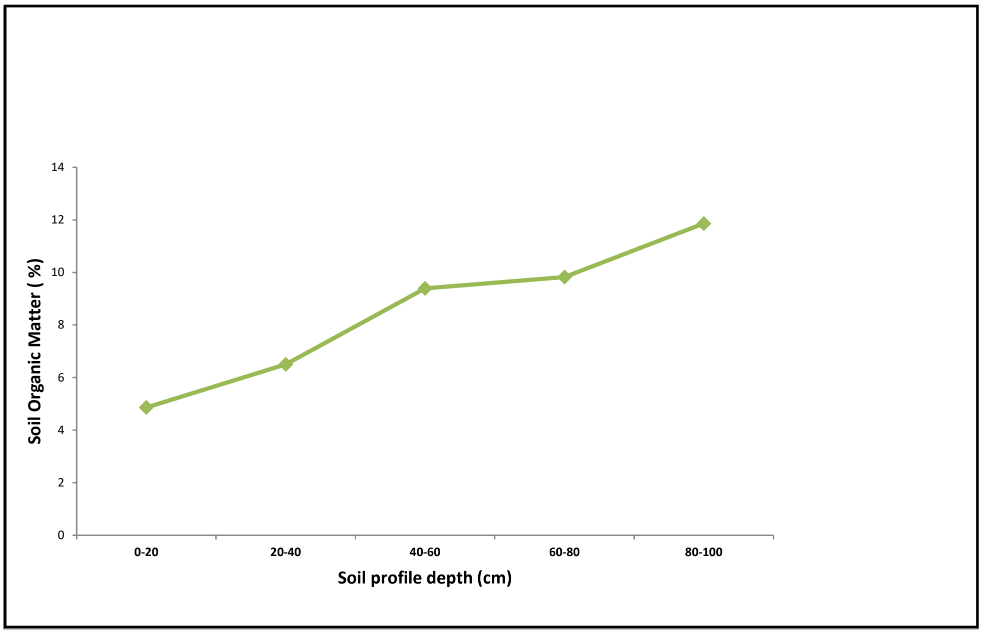

Figure 1. Distribution of soil organic matter in a vegetable grown valley soil of the Makerere University Agricultural Research Institute, Kabanyolo in central Uganda

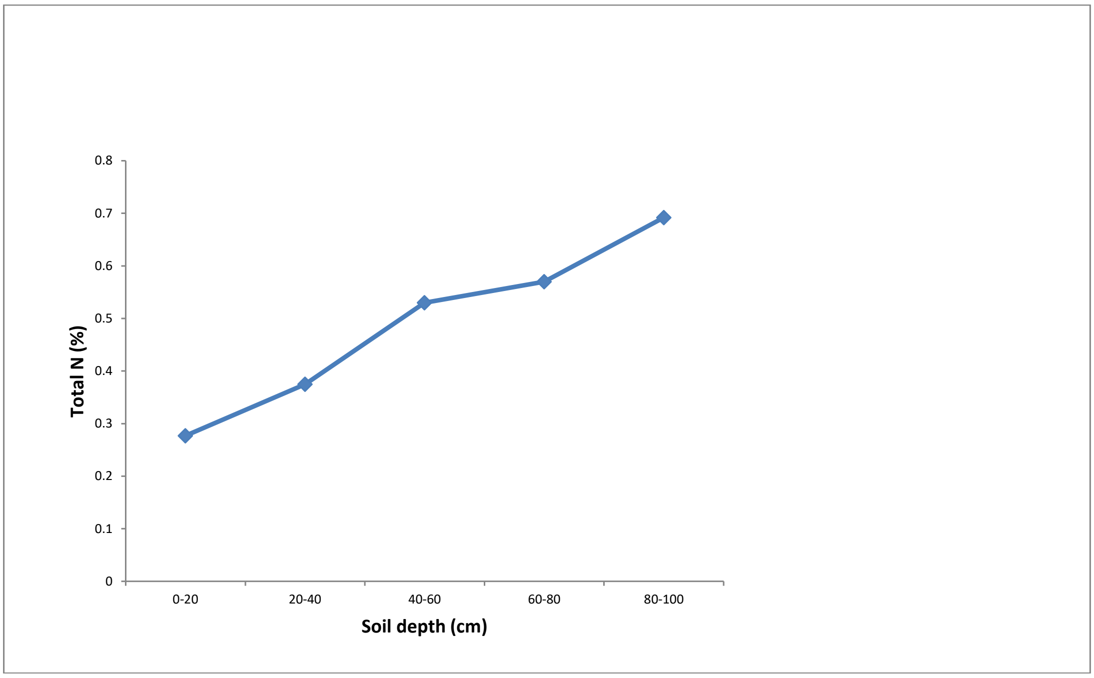

Figure 2. Distribution of total nitrogen in a vegetable grown valley soil of the Makerere University Agricultural Research Institute, Kabanyolo in central Uganda

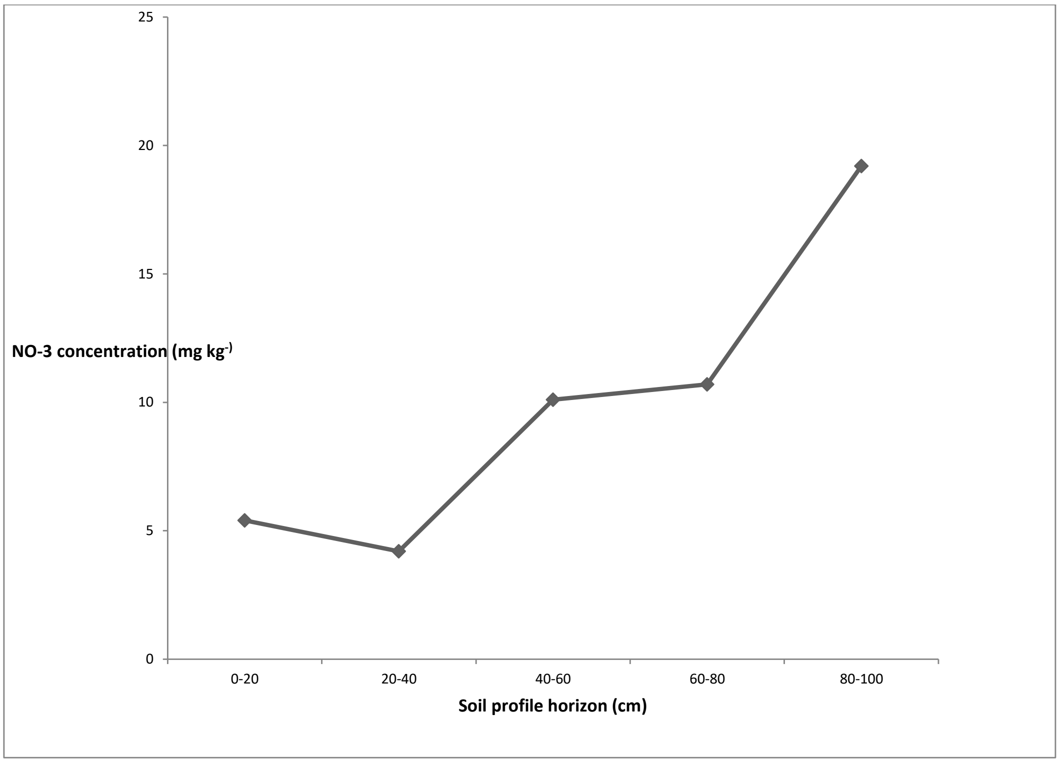

Figure 3. Distribution of nitrate in a vegetable grown valley soil of the Makerere University Agricultural Research Institute, Kabanyolo in central Uganda

CONCLUSION

It is clear from this study that, whereas it is inevitable to use soil fertility inputs to bolster crop production, the process ought to be pursued cautiously to avoid negative impacts on the environment. It is often argued that the quantities of soil fertility inputs accessed and used in Uganda are invariably meager at small scale level to impact the environment. This is also stretched to the sub-Saharan level where an average of <6 kg of fertiliser is believed to be used per hectare annually per capita. Whereas this argument may be valid in the short run, it may be questionable in the long term if the use is not well targeted and regulated, especially in the horticultural sector where the consistent high demand may oblige farmers to overstretch production mechanisms available to them.

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STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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