Plant nutrient uptake by the maize crop under different erosion levels and granitic sandy soils of Zimbabwe

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Abstract
Sheet erosion selectively removes fine soil particles like organic matter and clay, which are critical in soil productivity as they determine the nutrient-supplying capacity as well as the water-holding capacity of the soils. The process is often insidious and may go unnoticed until yields decline drastically. The use of hybrid seed and fertilizers often masks the seriousness of the problem, but it is not known to what extent. This study, therefore sought to assess the uptake of plant nutrients (N, P, K) under five different erosion levels and two fertilizer levels (normal and double). Different erosion levels were achieved by removing different depths of topsoil (scalping). The results showed that nutrient uptake decreased significantly with increase in erosion (N and P at $P<0.001$; K at $P<0.002$). The fertilizer use efficiency decreased drastically from uneroded to severely eroded plots. Doubling the fertilizer amount only increased uptake slightly but fertilizer use efficiency remained overall lower than under normal fertilized plots. Soil conservation is the key to sustained soil productivity through maintenance of soil structure and optimal uptake of water and plant nutrients.

Key words: *soil productivity, soil erosion, plant nutrient uptake, fertilizer use efficiency*

Introduction

Soil erosion is rampant in Zimbabwe's smallholder farming areas, due to a number of factors including inherently infertile and highly erodible soils (Grant, 1979), land pressure leading to over-utilization of land (Moyo, *et al.*,1991) and the erratic and high intensity rainfall (Elwell, 1975). Mono-cropping of poor cover crops (cereals) and grazing of fields during winter also enhance the problem of sheet erosion. To conserve land and reduce the incidence of soil erosion and land degradation, contour ridges, waterways and storm drains were constructed and have generally been effective in controlling rill and gully erosion. Sheet erosion, often insidious and involving the selective removal of fine soil particles, clay and organic matter, is still a major problem in these areas (Elwell, 1984). This type of erosion results in loss of soil productivity as the fine soil particles are the nutrient-supplying capacity of the soils.

Sheet erosion influences yield by changing soil chemical, physical and biological characteristics, through preferential removal of fine particles mainly in the A-horizon (USDA, 1998; Al-Kaisi, 2008). This results in the potential loss of soil productivity, as a result of plant nutrients loss, poor soil structure, reduced available water capacity, poor tilth and reduced infiltration rate (Dracup, *et al.*,1980; Lal, 2009; Mainuddin and Kirkby, 2009). Nutrient losses resulting from sheet erosion present one of the most important factors affecting productivity of the soils in the smallholder farming areas of Zimbabwe (Munodawafa, 2007). While work has been carried out to quantify the extent to which nutrients are lost with sheet erosion under granitic sands and semi-arid conditions of Zimbabwe (Moyo, 2003), the effect of soil erosion on some soil productivity determining parameters has not been given much consideration. The loss of plant nutrients with sheet erosion is accompanied by reduction in soil fertility but the erosion-yield relationships as well as the degree to which the crops can access the plant nutrients under different erosion levels is still not clear. The aim of this study was to assess plant nutrient uptake by the maize crop under different erosion levels and thus relate to reduction in yield and soil productivity. Scalping of the soil surface, known as desurfacing, was used to represent the different soil erosion levels. Desurfacing is a means of accelerating erosion by the removal of a unit layer of topsoil on the assumption that this is simulating the removal of the same unit depth by the natural process of erosion (Lowery and Larson, 1995).

Materials and methods

Experimental site

The study was carried out at Makoholi Research Station, which is located in the semi-arid region of southern Zimbabwe. This region is characterised by erratic and unreliable rainfall pattern both between and within seasons and the average annual rainfall is between 450 and 650 mm (Thompson and Purves 1981). The station lies within Natural Region IV at an altitude of about 1200 m (Thompson, 1967). The soils are inherently infertile, pale, coarse-grained granite-derived sands (Makoholi 5G) of the fersiallitic group (Ferralic Arenosols). Arable topsoil averages between 82 and 93% sand, 1 and 12 % silt and 4 and 6% clay (Vogel, 1993). The organic matter content is low ~ 0.8%, while pH ($CaCl_2$) is as low as 4.5. The soils are generally well drained but some sites have a stone line between 50 and 80 cm depth (Munodawafa, 2007).

Experimental design, erosion plots and agronomic details

The erosion plots of 10 x 5m were laid out in a randomised split plot design, with the blocks replicated three times. The plots were excavated to different depths of 0; -5; -10; -15 and -20 cm to represent erosion levels of 1 (nil); 2 (slight); 3 (medium); 4 (high) and 5 (severe) respectively. All plots were then ploughed to 23 cm depth and subdivided to allow for two fertilizer levels. The first level (normal fertilizer, optimal for these conditions) received 200 kg ha^{-1} of basal fertilizer (to give a ratio of 16 kg N; 12 kg P; 12 kg K) and 100 kg ha^{-1} of top dressing (34.5 kg N), while the second level (double fertilizer) received 400 kg ha^{-1} of basal fertilizer (32 kg N; 24 kg P; 24 kg K) and 200 kg ha^{-1} (69 kg N) of top dressing. All plots were planted to maize (*Zea mays L*) at 36 000 plants/ha. Sub-plots of 8 m x 3 m were marked out in each plot and the crop within this area was harvested and weighed. Plant material was analysed for N, P and K, however the cobs, stover and grain were treated as different entities. For each nutrient the amount found in the different plant material entities was summed up to represent the amount of total nutrient taken up by the crop.

Results and discussion

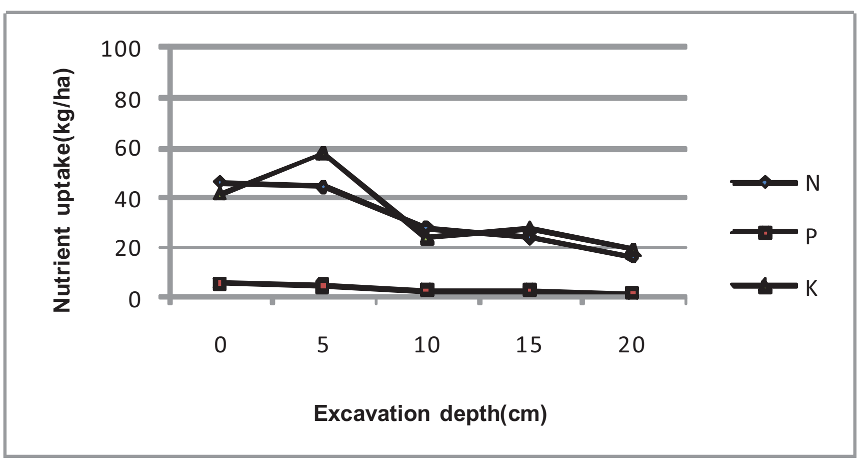
Nutrient uptake

The amount of a nutrient a crop takes up from a soil, depends not only on the amount of that nutrient in the soil, but also on the availability of other nutrients. In this study no effort was made to differentiate between the inherent nutrients and the ones added through fertilizer application. Thus the amount of the nutrients taken up by the crop under a given erosion and/or fertilizer level serves to emphasise the nutrient availability (soil condition) and/or the indirect contribution of these nutrients towards the end product (yield).

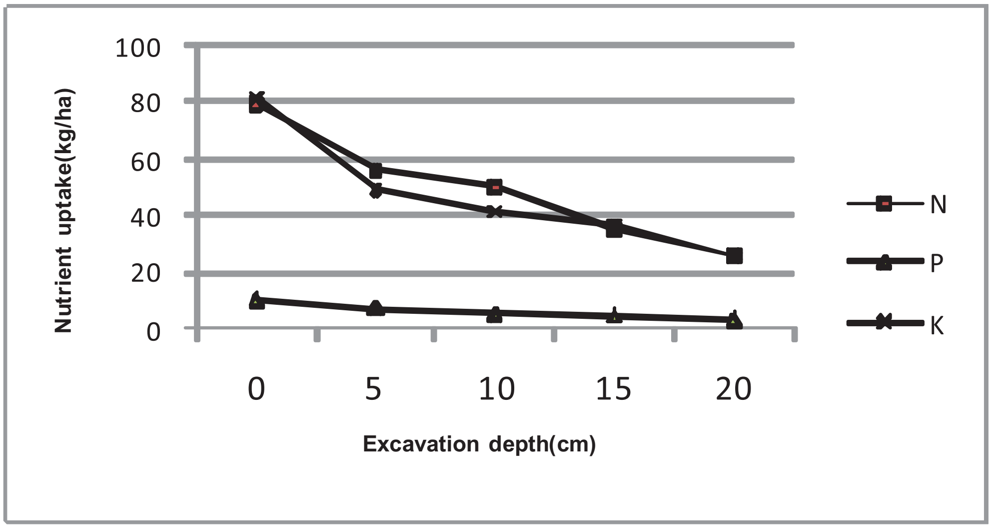
Nitrogen

There was a decrease of N uptake with the increase in erosion. On average N uptake decreased from 63 kg ha^{-1} on uneroded land to 21 kg ha^{-1} on severely eroded land. The variation of N uptake under the different erosion levels was highly significant at $P < 0.001$. N uptake under normal fertilizer application averaged 32 kg ha^{-1}, while under double fertilizer it averaged 50 kg ha^{-1}. This difference in N uptake under the two fertilizer levels was also highly significant at $P < 0.001$. Doubling the fertilizer amount only boosted the N uptake, but did not double N uptake. Figure 1 shows the trend of N uptake within the different erosion levels under normal and double fertilized plots respectively.

The relationship between N uptake and erosion level for both fertilizer levels, using regression analysis, showed that indeed N uptake decreased with increasing erosion but the decrease was not uniform across all erosion classes. No one equation could be used to estimate the decrease of N uptake without compromising the accuracy, i.e. R^2 value. Under normal fertilizer, depth (soil loss) accounted for 76.9% variation of N uptake and N uptake decreased as shown in Table 1. Altogether N uptake decreased by 30 kg ha^{-1} from uneroded land to severely eroded land. Depth accounted for 66.1% of N uptake variation under double fertilized plots and N uptake was estimated to decrease with increasing erosion as shown on Table 1. Under this fertilizer level N uptake was reduced by 54.2 kg ha^{-1} from uneroded to severely eroded land.



(a)



(b)

Figure 1: Nutrient uptake under (a) normal fertilized plots and (b) double fertilized plots for the different erosion levels over two seasons at the Makoholi Contill site

Under normal fertilized plots 50.5 kg ha^{-1} N were applied as fertilizer. The amount of fertilizer taken up by the crop, for the different erosion levels, was expressed as a percentage relative to the amount applied. Under erosion level 1, an equivalent of 92% of applied N was taken up by the crop, while under erosion level 2 this amount was reduced to an equivalent of 88%. The crop under erosion levels 3, 4 and 5 took up an estimated 55%, 47% and 32% respectively. The double fertilized plots received 101 kg ha^{-1} N and N uptake was as follows: An equivalent of 79% for erosion level 1; 56% for erosion level 2; 50% for erosion level 3; 36% for erosion level 4 and only 26 % for erosion level 5. It is clear that the fertilizer use efficiency is higher on uneroded plots, but more-so on normal fertilized plots compared to double fertilized plots. This indicates once again, that applying more fertilizer does not directly influence fertilizer uptake and the resultant yield.

Phosphorus

P uptake decreased from 7.8 kg ha^{-1} under uneroded plots to 2.2 kg ha^{-1} under severely eroded plots (Figure 1). Analysis of variance showed that the difference in P uptake among the erosion levels was significant at $P < 0.001$. On average the P uptake under normal fertilized plots was 3.3 kg ha^{-1}, while under double fertilized plots it was 5.8 kg ha^{-1}. This difference was also significant at $P < 0.001$.

Regression analysis showed that depth accounted for 64.9% of the variation of P uptake under normal fertilized plots. P uptake was estimated to decrease from uneroded land to the other erosion levels as follows: by 1.11 kg ha^{-1} to erosion level 2; by 3.07 kg ha^{-1} to erosion level 3; by 3.32 kg ha^{-1} to erosion level 4 and by 4.07 kgha^{-1} to erosion level 5. Under double fertilizer, depth accounted for 66.1% of the variation of P uptake. The estimated decrease of P uptake from uneroded land was as follows: 2.94 kg ha^{-1} to erosion level 2; 5.08 kg ha^{-1} to erosion level 3; 5.51 kg ha^{-1} to erosion level 4 and 7.19 kg ha^{-1} to erosion level 5.

Table 1: Estimated decrease of nutrient uptake by the maize crop with increased erosion at Makoholi Contill site

Treat	Estimated N uptake (kg ha^{-1})	N uptake % (relative to applied fertilizer)	Estimated P uptake (kg ha^{-1})	P uptake % (relative to applied fertilizer)	Estimated K uptake (kg ha^{-1})	K uptake % (relative to applied fertilizer)
Normal fertilizer						
0	46.20	92	5.64	47	40.77	340
5	44.16	88	4.53	38	57.70	481
10	27.69	55	2.56	21	23.85	199
15	23.63	47	2.32	19	27.42	229
20	16.21	32	1.57	13	18.94	158
R^2	0.769		0.649		0.606	
s.e.d.	3.69		0.619		6.20	
P	0.025		NS		NS	
Double fertilizer						
0	79.98	79	9.99	42	81.5	340
5	56.78	56	7.05	29	49.2	205
10	49.98	49	4.91	20	41.4	173
15	35.88	36	4.18	17	36.6	153
20	25.78	26	2.80	12	25.6	107
R^2	0.661		0.661		0.420	
s.e.d.	7.44		1.00		11.2	
P	NS		NS		NS	

The amount of P applied under normal fertilized plots was 12 kg ha^{-1} and an equivalent of only 47% of this amount was taken up under erosion level 1. This amount depreciated with increased erosion as follows: 38% for erosion level 2; 21% for erosion level 3; 19% for erosion level 4 and 13 % for erosion level 5. The double fertilized plots received 24 kg ha^{-1} P and the fertilizer uptake in relation to applied fertilizer also followed the same trend: an equivalent of 42% for erosion level 1; 29% for erosion level 2; 21 % for erosion level 3; 17% for erosion level 4 and 12 % for erosion level 5. The P uptake in relation to applied fertilizer was overall very low as compared to N uptake, e.g. an equivalent of 92 % of applied N was taken up under normal and uneroded land compared to an uptake of only 47% of applied P on the same plots. This means that a higher percentage of P is lost through fixation, leaching or with erosion.

Potassium

The amount of K that was taken up by the maize crop was nearly as much as N uptake (Grand means of 40.6 kg ha^{-1} for N uptake and 40.3 kg ha^{-1} for K), despite the different amounts that were applied (12 kg ha^{-1} of K compared to 50.5 kg ha^{-1} of N). Generally K uptake also declined with the increase in erosion (61 kg ha^{-1} on uneroded land to 22 kg ha^{-1} on severely eroded land). However, under