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Quantifying the Effects of Crop and Soil Management Practices on Soil Productivity Using N as a Soil Quality Indicator

M.A.N. Anikwe

Keywords: Quantitative evaluation- Safe and unsafe cropping systems- Soil productivity- Maize and groundnut

Summary

The development and evaluation of soil productivity index for estimating safe (restorative) and unsafe (depletive) cropping systems using N as a soil quality indicator was carried out at Nsukka southeastern, Nigeria. The study was carried out during the 1996, 1997, 1998 and 1999 planting seasons in a Typic Paleustult using two tillage systems and four other management practices (poultry droppings + NPK, Mulch + NPK, NPK alone and no amendment). These were laid out in split – plots in randomized complete block design replicated three times using maize and groundnut as test crops. The percent changes in soil post – harvest N content in relation to the change in seed yield of maize and groundnut were used to develop an index of productivity rating to be used by farmers to calculate safe or unsafe cropping system. Results from the study indicated that soil post - harvest N content had good relationship with seed yield (r= 0.95 and r= 0.94 for maize and groundnut respectively) and that the manure + NPK plots, with the highest calculated productivity index (+ 0.7 for maize and + 0.9 for groundnut) were the plots with vice the highest seed yield of maize and groundnut, respectively. Conversely, the plots with the lowest ratings (unamended maize plots with - 0.6 and unamended groundnut plots with - 0.3) were those with the lowest seed yields. In the residual planting year (1999), plots with the highest ascribed productivity indices were the plots with the highest seed yield of maize and groundnut and vice versa*. Thus the calculated productivity index values could be used by a farmer to predict* a priori *the effect of a given management practice he plans to adopt.*

Résumé

Quantification d'effets de plantes et de pratiques agricoles sur la productivité du sol par utilisation de l'azote comme indicateur de la qualité du sol

Le développement et l'évaluation de l'indice de productivité pour estimer les effets (déplétifs ou restauratifs) des systèmes de culture sur le niveau de fertilité des sols, en utilisant l'azote comme indicateur de la qualité, ont été réalisées à Nsukka dans le sud-est du Nigeria pendant les saisons culturales de 1996, 1997, 1998 et 1999. L'essai a été conduit en plantant le maïs et l'arachide sur un sol de type «Paleustult». Le dispositif expérimental était en parcelles divisées dans des blocs aléatoires complètement randomisés avec trois répétitions. Deux systèmes de labour et quatre techniques culturales (fumure de volaille + NPK, paillis + NPK, NPK pure et sans amendement) ont été quantifiés. Les changements de la teneur en azote des sols avant et après la récolte en rapport avec les changements du rendement en graines de maïs et de l'arachide ont été utilisés pour développer un indice permettant d'évaluer la productivité des sols utilisable par les agriculteurs pour estimer la durabilité des systèmes de culture.

Les résultats obtenus ont montré une corrélation entre la quantité de l'azote post-récolte et le rendement en graines de r= 0,95 et 0,94 respectivement pour le maïs et pour l'arachide. Il a été en plus constaté que les parcelles fertilisées par la fumure + NPK, avaient un indice de productivité plus élevée de + 0,7 pour le maïs et de + 0,9 pour l'arachide, et avaient également le plus grand rendement en graines. Par contre, les parcelles avec les indices plus faibles sans amendement (- 0,6 pour le maïs et - 0,3 pour l'arachide) présentaient également le plus faible rendement. Lors de la campagne de semis (1999), les parcelles qui présentaient les indices de productivité les plus élevés étaient également celles où s'observaient les plus hauts rendements en graines de maïs et de l'arachide et vice versa*. Les valeurs calculées de l'indice de productivité devraient pouvoir être utilisées par les fermiers pour prédire à priori l'effet d'une technique culturale qu'ils envisagent adopter.*

Department of Agronomy, Faculty of agriculture, Enugu state, University of science and technology, P.M.B. 01660, Enugu, Nigeria.

Author's e–mail address: anikwema@yahoo.co.uk

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Introduction

There are many stresses experienced by a land resource system and its soils. Such stresses as soil acidification, salinization, poor drainage and erosion cause reduction in the productive capacity of soil. Just as we can assess human health, we can evaluate soil quality and health (3). Larson and Pierce (7) proposed that a minimum data set of soil parameters should be adopted for assessing the health of world soils, and that standardized methodologies and procedures be established to assess changes in the quality of these factors. There are no reliable, practical methods of assessing or evaluating soil quality/health, although some research reports have established a conceptual framework for assessing this (6). According to Mausbach and Seybold (8) the assessment of soil quality presumes that procedures exist to measure it and standards have been developed to determine the relative quality of soil under various land uses and management systems. Assessments of soil quality they concluded, can be, in the simplest form, visual observations of soil quality or may be very complex involving many laboratory analyses and the calculation of soil quality indices. Assessments of soil quality in most cases require monitoring of changes/trends in soil quality over time. This approach involves selecting indicators that are sensitive to productivity of crops and measuring the changes in selected indicators reflect the combined effects of land use and climate. Soil quality is then evaluated by the trend lines as described by Pierce and Larson (12) and, Larson and Pierce (7). Mausbach and Seybold (8) noted that if the change in a soil quality indicator is positive and more is of better quality, then the soil could be regarded as improving or aggrading in quality. Conversely, if the trend line is negative, then soil quality is degrading.

One of the major handicaps of presently used methods of assessing soil quality is that too many indicators have variable effects and it is always difficult to establish baseline values for each indicator. Similarly, some measurement parameters may be important in a particular area and unimportant in other areas, this makes it impossible for generalization to be made. Finally, some indicators of soil quality are not directly sensitive to yield of crops and the fact that only one indicator cannot be used often adds to the confusion. According to the United States National Soil Erosion Soil Productivity Research Planning Committee (14) accurate estimates of future soil productivity are essential in making agricultural policy decisions and for planning the use of land from field scale to national level. Such task is enormous because it requires a method of quantifying soil productivity, large soil databases and a means of handling large quantities of information. Researchers are making effort to quantify the relationship between soil degradation and soil productivity. Wang and Gong (15) elucidated that understanding the effects of land use and soil management practices on soil quality has been identified as one of the most important goals of modern soil science.

The objectives of this work were (a) to quantitatively evaluate the restorative and depletive effect of some crop and soil management practices on soil productivity using N as a soil quality indicator (b) to develop a soil productivity index for estimating safe (restorative) and unsafe (depletive) cropping systems using N as a soil quality indicator. The perspective of this kind of work is to produce promising approaches that will be used by farmers to predict *a priori* the effect of crop and soil management practices on soil productivity.

Material and methods

1. Soil characterization

This study was carried out for four consecutive planting seasons (1996, 1997, 1998 and 1999) on the University of Nigeria Teaching and Research Farm at Nsukka, Nigeria (latitude 06 ^{0}52’ N, longitude 07 ^{0}24’ E, mean elevation 400 m above sea level) with an average annual rainfall of 1600 mm (9). The soil is deep, porous and red to brownish red, derived from sandy deposits of false-bedded sandstone. It has an isohyperthermic temperature regime and is classified as Typic Paleustult (11).

2. Field study

A total land area of 64 x 28.5 m (1824 m^2) was mapped out for the experiment. The experimental design was split-plot on a randomized complete block with two tillage techniques on the main plots and eight management practices on the sub-plots. The field was divided into 3 blocks measuring 20.5 x 28.5 m (584.25 m^2) each. These were demarcated by 1 m wide pathways. Each block was further, divided into 8 experimental plots of 3 x 20 m (60 m^2) each with 0.5 m alleys between them. The tillage techniques were - no tillage and 30 cm tillage on raised beds. The crop management practices were, NPK fertilizer, Manure + NPK fertilizer, Mulch + NPK fertilizer, and no application on maize and groundnut.

Weeds were removed with hoes in the “no till” plots and seed holes were made for planting while in the 30 cm tilled plots, conventional tillage implement (hoes) was used to till the soil to 30 cm depth.

The maize variety used was Oba super II, hybrid variety while the groundnut variety used was the erect type (Virginia, cultivar “Nwakara”). Poultry droppings was used as a source of organic manure at the rate of 20 t.ha^{-1}, Grass mulch (*Paspalum spp*) was used for the experiment and was applied at the surface at the rate of 3 t.ha^{-1}. Fertilizer (NPK 15: 15: 15) was applied banded at 5 cm depth and 10-15 cm radius at the rate of 300 kg.ha^{-1}. Maize and groundnut seeds were manually planted at 25 x 75 cm spacing, 5 cm deep and two seeds per hole in the appropriate plots. They were thinned down to one seed per hole, one week after emergence leaving 320 plants per plot or 53 plants.ha^{-1}. Lost stands were replaced. The mulch and organic manure (poultry droppings) were applied at the appropriate plots one-week before planting.

The experimental area was kept relatively weed-free throughout the span of the experiment. This was done at three-week interval from planting date to harvest.

3. Observation and data collection

Yield data and soil samples were collected from different plots at the end of each planting season and used as a measure of assessment of the depletive and restorative effects of soil and crop management practices.

4. Laboratory methods

A composite soil sample (collected from 6 points) from each plot was analyzed in the laboratory for total nitrogen content using the Macro-Kjeldhal's method as proposed by Bremner (2).

5. *Data analyis*

The data collected from the experiment was analyzed using correlation, regression and analysis of variance test based on the split-plot design in randomized complete block according to the procedure outlined by Steel and Torrie (13).

Results and discussion

1.Soil properties and crop yield

The soil of the study site is red in color with a shallow a horizon. The structure is granular to massive and the horizon boundaries are diffuse and irregular (11). The lack of mottles indicates that they are well-drained soils. The detailed physico-chemical characteristics of this soil have been discussed earlier by Mbagwu (10), Igwe *et al.* (5) and Anikwe *et al.* (1).

The results of the study show that tillage did not significantly influence grain yield of maize and groundnut in the three seasons. Grain yield of maize and groundnut were significantly affected by four other soil management practices (Table 1). Cumulative results show that maize plots amended with manure + NPK had an over 8-fold increase in grain yield relative to the control. Other treatments (mulch + NPK and NPK alone) did not statistically affect grain yield of maize relative to the control (unamended plots). In groundnut plots amended with manure + NPK, cumulative data show that grain yield also increased ($P < 0.05$) by 123% relative to the control.

2. Soil productivity index (PI) for estimating safe or unsafe cropping systems

The percentage change in N content in relation to the change in crop seed yield under the different crop and soil management practices is presented in table 2.

Table 1

Effect of crop and soil management practice on grain yield (kg.ha^{-1}) of maize and groundnut during the 1996,1997 and 1998 planting season. Seed yield (kg.ha^{-1})

Crop	Management practice	1996	1997	1998
Maize				
	NPK	1270	1194	1124
	Manure + NPK	4600	5344	6200
	Mulch + NPK	1440	1386	1328
	Control	730	680	620
	FLSD (P= 0.05)	171.7	69.7	66.69
Groundnut				
	NPK	640	608	580
	Manure + NPK	990	1181	1400
	Mulch + NPK	603	670	760
	Control	590	610	544
FSLD (P= 0.05)		48.06	45.53	20.10

Table 2
Percent change in post harvest N and seed yield of maize and groundnut under different management practices

Crop	Management practice	Percent change in N			Percent change in seed yield	
		1996	1997	1998	1997	1998
Maize	NPK	-2.86	-2.94	-2.54	-5.98	-5.86
	Manure + NPK	+7.19	+5.33	+7.6	+16.17	-16.02
	Mulch + NPK	-1.38	-1.49	-1.42	-3.75	-4.18
	Control	-5.7	-6.0	-4.7	-6.84	-8.8
Groundnut						
	NPK	-1.38	-1.49	-1.42	-5.0	-4.6
	Manure + NPK	+10	+9.0	+8.4	+19.3	+18.5
	Mulch + NPK	+2.86	+2.78	+2.7	+11.1	+13.4
	Control	-2.85	-2.94	-4.5	-3.3	-5.9

NB $\frac{\text{Pre-cropping N= Post harvest N in previous year - Post harvest N in the current year}}{\text{Post harvest N in previous year}} \times \frac{100}{1}$

$\frac{\text{Pre-cropping yield= Yield in the previous year - yield in the current year}}{\text{Yield in previous year}} \times \frac{100}{1}$

These were used to develop an index of productivity rating (PI) to be used by farmers to calculate safe and unsafe cropping systems. The ascribed productivity index ratings are presented in table 3.

Table 3
Ascribed soil productivity index under eight management practices

Crop	Management practice	Productivity index (PI)
Maize	NPK	- 3.0
	Manure + NPK	+ 7.0
	Mulch + NPK	- 1.0
	Control	- 6.0
Groundnut	NPK	- 1.0
	Manure + NPK	+ 9.0
	Mulch + NPK	+ 3.0
	Control	- 3.0

NB ascribed productivity index (PI) was derived directly from the percent N change in each year for each management practice and is defined as average annual percent change in soil post harvest Nitrogen content.

The productivity index was derived directly from percentage change in soil N between 1996 and 1998 cropping seasons. The average annual percentage change in soil N for eight management practices was used as a dimensionless productivity index (PI). Because crop yields on these management practices had linear relationships with soil N content (Table 2), it is assumed that soil productivity would increase or decrease according to the changes in soil N content. The results (Table 3) indicate that the highest rating was obtained in groundnut plots amended with poultry droppings + NPK (+ 9) whereas lowest rating (- 6) was observed in unamended maize plots. Similarly, maize plots amended with poultry droppings + NPK had productivity rating of + 7 whereas unamended groundnut plots recorded a productivity rating of - 3. These results also reveal that maize depletes soil productivity more than groundnut. More specifically, these ratings are meant to express the effect of growing maize or groundnut under different soil management practices on soil productivity. The productivity index is further expressed in the form in table 4.

Table 4
Soil productivity ratings for two crops and four management practices

Crop /soil management practice	Soil productivity index (PI)
1. Row crop (maize without amendments)	- 6.0
2. Application of 45 units of fertilizer to maize (300 kg. ha^{-1} NPK 15:15:15)	- 3.0
3. Application of manure + NPK to maize (20 $t.ha^{-1}$ poultry droppings + 45 units of fertilizer)	+ 7.0
4. Application of mulch + 45 units of fertilizer to maize (3.0 $t.ha^{-1}$ grass mulch)	- 1.0
5. Row crop (Groundnut without amendment)	- 3.0
6. Application of 45 units of fertilizer to groundnut	- 1.0
7. Application of manure + 45 units of fertilizer to groundnut	+ 9.0
8. Application of mulch + 45 units of fertilizer to groundnut	+ 3.0

Cook (4) assumed that:

– the productivity indices such as those shown in Table 4 would apply to soils to which the crops were edapho-climatically adapted,

– that full yields would be necessary or soil building effects could not be taken as credit,

– that credit for fertilizers should be taken only to the extent that yields were increased,

– that credits for manure (poultry droppings) could be increased or reduced depending on the nutrient content (quality) of the material.

3. Calculation of safe and unsafe cropping system

A productivity index can be used to calculate a safe or unsafe cropping system thus helping the farmer to predict *a priori* the effect of a given management practice he plans to adopt. For example, growing sole maize without any amendment to the soil for one year will deplete soil fertility. This will result in soil productivity index rating of - 6, for each cropping season (Table 3). It represents a N loss of about 62 $kg.N.ha^{-1}$ in one season. Soil productivity can be improved in such a farm by adding poultry droppings + NPK in the second year. Thus soil productivity rating would be - 6 (for the first year) and + 7 (in the second year). This would be a better option for the farmer, as he would record soil productivity index of + 1 after the second year of planting.

The following hypothetical example (Table 5) is used to illustrate the use of this productivity index (PI) and to determine whether productivity would increase or decrease in the different cropping systems adopted.

Assume a four-hectare farm; each hectare is made up of a different management practice for five years as found in table 5. To calculate the productivity index at the end of the five years using productivity index table (Table 3) we have the PI values in table 6.

Table 5
Hypothetical five-year cropping programme using different crop and soil management practices

Year	1	2	3	4
1.	Sole maize + manure + NPK	Sole maize + NPK	Sole groundnut + manure + NPK	Sole maize, alone
2.	Sole maize , alone	Sole groundnut , alone	Sole maize, alone	Sole maize, alone
3.	Sole groundnut + mulch + NPK	Sole groundnut + mulch + NPK	Sole groundnut, alone	Sole maize, alone
4.	Sole groundnut + mulch + NPK	Sole groundnut + manure + NPK	Sole maize, alone	Sole maize ,alone
5.	Sole groundnut + manure + NPK	Sole groundnut + manure + NPK	Sole maize + mulch + NPK	Sole maize, alone

Table 6
Calculated productivity index for the crop and soil management practice on table 5

Year	1	2	3	4
1	+ 7.0	- 3.0	+ 9.0	- 6.0
2	- 6.0	- 3.0	- 6.0	- 6.0
3	+ 9.0	+ 3.0	- 3.0	- 6.0
4	- 1.0	+ 9.0	- 6.0	- 6.0
5	+ 9.0	+ 9.0	- 1.0	- 6.0
Total PI	+ 18.0	+15.0	- 7.0	- 30.0

This hypothetical five year cropping programme can show the farmer how to select the best cropping system to adopt depending on specific needs and availability of resources and inputs. The farmer would adopt the cropping system in field 1 if there were no other limitations to be considered. On the other hand, if he would not be able to adopt the practice in field 1, then, the practice in field 2 would be his next available alternative. This would be followed by fields 3 and 4 in that order as far as soil productivity is the basis for the choice. The hypothetical case shows that after ten years, the soil of field 1 would have the highest productivity whereas that of field 4 would have the lowest productivity. According to Cook (4), a positive productivity index would indicate a build-up of the soil productive capacity to optimum level.

4. Validation of the productivity index model

In the 1999-planting season, maize and groundnut were planted in their respective plots without amendments. The aim was to find out the residual effect of the crop and soil management practices on seed yield of maize and groundnut. The results from this experiment (Table 7) show a highly significant correlation between cumulative ascribed PI and residual yield of maize and groundnut (r= 0.99 at P= 0.01) respectively.

These results show that the ascribed productivity index rating can actually be used to estimate the depletive or restorative power of certain crop and soil management practices adopted by farmers.

The results (Table 8) show that plots with the highest post-harvest N content in 1998 season (third year) correspond to the plots with the highest residual seed yield of maize and groundnuts respectively.

Table 7
Relationship between ascribed productivity index (X) and some measured productivity indicators (y)

Parameter	Correlation coefficient (r)
PI versus post harvest N content (1996-1999)	0.92**
PI versus post harvest N 1998 alone	0.99**
Cumulative PI (3 years) Vs residual yield (1999) (maize)	0.99**
Cumulative PI (3 years) Vs residual yield 1999 (Groundnut)	0.98**

** Significant at P= 0.01

Also unamended plots with the lowest PI were the plots with the lowest post-harvest N in 1998 season and the plots with the lowest residual seed yield of maize and groundnut respectively.

Yield reductions were higher in maize plots compared to groundnut plots. For example, in maize plots amended with poultry droppings + NPK, a yield reduction of 80% was recorded in the residual planting year. This is in contrast with the corresponding groundnut plot where a yield reduction of 18% was recorded. Similarly, yield reduction of 62, 58 and 36% were obtained in maize plots amended with NPK alone, mulch + NPK and unamended plots respectively whereas corresponding groundnut plots recorded 5.5, 2.8 and 2.5% reduction in seed yield for plots amended with NPK alone, mulch + NPK and unamended plots respectively in the residual year. Thus maize exploits more N from the soil compared to

Table 8
Ascribed productivity index for two plant types and four management practices for 1996,1997 and 1998, Post –harvest soil N content (kg. ha^{-1}) (1998) and residual seed yield (kg.ha^{-1}) of maize and groundnut during the 1999 planting season

		Year (PI)			+Cumulative	Post harvest N (kg.ha^{-1})	*residual yield
		1996	1997	1998	PI	1998	1999
Maize	NPK	- 3	- 3	- 3	- 9	997	428
	Manure + NPK	+ 7	+ 7	+ 7	+ 21	1318	1225
	Mulch + NPK	- 1	- 1	- 1	- 3	1039	564
	Control	- 6	- 6	- 6	- 18	916	394
	F-LSD (P= 0.05)					186	63.73
Groundnut							
	NPK	- 1	- 1	- 1	- 3	1039	548
	Manure + NPK	+ 9	+ 9	+ 9	+ 27	1411	1152
	Mulch + NPK	+ 3	+ 3	+ 3	+ 9	1178	739
	Control	- 3	- 3	- 3	- 9	976	530
	F-LSD (P= 0.05)					232.5	28.29

* Residual planting year (N° applications were made on the plots)
+ Cumulative PI (Summation of PI for 1996,1997 and 1998).

groundnut. This trend is clearly depicted in table 8. The groundnut plots had higher cumulative PI than the corresponding maize plots. Maize depletes soil N more than groundnut by about 6-7%. Mbagwu (10) reported that a 13% decrease in N content of unamended maize plots led a 33 percent decrease in yield and showed that N had good correlation with maize yield (r= 0.82 at P= 0.05).

Conclusion

Results from this work indicate that the ascribed productivity index method can be used to predict the restorative or depletive power of crop and soil management practice. It must be emphasized however, that N is not the only factor that determines soil productivity. In fact, many factors interactively govern the appreciation and depreciation of soil productivity in a natural system like the soil. Although, the ascribed productivity index is dimensionless, the crop and soil management practices with negative PI correspond to those with negative changes in seed yield and *vice versa*.

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M.A.N. Anikwe, Nigerian, PH.D. Soil science, Senior lecturer/researcher & head, Department of agronomy and ecological management, Enugu state University of science and technology, Enugu, Nigeria. Author’s e–mail address: anikwema@yahoo.co.uk.