

A. Belay · A.S. Claassens · F. C. Wehner

Effect of direct nitrogen and potassium and residual phosphorus fertilizers on soil chemical properties, microbial components and maize yield under long-term crop rotation

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Abstract A study was conducted in a long-term field experiment initiated in 1939 at the University of Pretoria, South Africa. The aim was to assess the long-term effect of direct N and K and residual P fertilizers on chemical and microbial properties of soil and grain yield of maize in rotation with field pea. Long-term fertilization resulted in decreased total organic C (TOC) and basic cation contents, and had an acidifying effect on soil. The decrease in TOC was greater in simple fertilizer treatments (N, P, or K) whereas basic cation contents and pH declined more in balanced fertilizer treatments (NPK). Levels of total N were higher in the balanced than in simple fertilizer treatments. Soil microbial biomass and numbers of bacteria, actinomycetes and fungi were influenced by, and exhibited qualitative changes in response to, long-term fertilization. Crop rotation also exerted effects on chemical and microbial properties of the soil. Maize grain yield showed significant increases due to balanced fertilizer treatments. Responses of maize to simple fertilizer applications were not beneficial in terms of yield returns. The results suggested that judicious use of inorganic fertilizers may, in the long-term, maintain soil quality and productive capacity.

Keywords Inorganic fertilizers · Maize yield · Microbial biomass · Microbial number · Soil chemical properties

Introduction

Inorganic fertilizers, especially N, P and K, not only serve to maintain or improve crop yields, but their application directly or indirectly causes changes in chemical, physical and biological properties of the soil. These changes, in the long-term, are believed to have significant influences on the quality and productive capacity of the soil (Acton and Gregorich 1995). However, available information is conflicting and uncertainties still remain about the long-term influences of inorganic fertilizers on soil quality and productive capacity. Some studies have shown that continued use of inorganic fertilizers may result in diminishing soil quality and productive capacity (Gliessman 1984; Doran and Werner 1990; Cassman and Pingali 1995; Doran et al. 1996). Others indicated both positive and negative effects (Hera and Mihaila 1981; Johnston 1994) or no noticeable changes (Aref and Wander 1998) on soil quality and productive capacity. These conflicting reports emphasize the need for research on long-term effects of inorganic fertilizer application on soil quality and productivity (Dobbs and Smolik 1996).

Effects of management practices on soil quality and productivity are best evaluated using long-term experiments (Mitchell et al. 1991; Nel et al. 1996). A long-term field experiment that has been ongoing for over 60 years at the University of Pretoria provided a unique opportunity for such a study. In the course of the experiment, investigations were conducted on growth, development and water use efficiency of maize (*Zea mays* L.) (Verwey 1974; Steynberg 1986), variability of certain individual treatments (Stoch 1983), and long-term grain yield trends during the period between 1939 and 1990 (Nel et al. 1996). Few attempts have been made to study the soil quality changes that have occurred in response to the long-term management practices imposed.

In a previous report (Belay et al. 2001) we discussed the influence of residual manure on selected nutrient elements and microbial properties of the soil. The present study assesses the effects of long-term N, P and K applications on chemical and microbial properties of the soil

A. Belay (✉) · A.S. Claassens
Department of Plant Production and Soil Science,
University of Pretoria, Pretoria 0002, South Africa
e-mail: asfaw_b@yahoo.com

F.C. Wehner
Department of Microbiology and Plant Pathology,
University of Pretoria, Pretoria 0002, South Africa

Present address:

A. Belay, Department of Botany and Microbiology,
University of Oklahoma, 770 Van Vleet Oval, Norman,
OK 73019, USA

and grain yield of maize in rotation with field pea (*Pisum arvense* Poir.). Conclusions are based on measurements of total organic C (TOC), total N (TN), available P (AP), pH, basic cations, microbial biomass and numbers, and crop yield which are considered to be determinants and good indicators of soil quality and productivity (Subian et al. 2000)

Materials and methods

The field experiment at the University of Pretoria (25°45'N, 28°16'E) in which the study has been conducted was established in 1939. Details about the site and experimental design have been provided by Nel et al. (1996) and Belay et al. (2001). Briefly, the experiment consists of five factors, namely water, N, P, K and manure, each at two levels (without or with application of a factor), laid out in a randomized complete block design with four replicates, thus comprising 32 treatment combinations on 128 plots. Plot size is 7.5×4.9m. The soil is a representative of well-leached soils that occur in many countries. It is classified as a loamy, mixed, thermic Rhodic Kandiudalf according to the USDA soil taxonomy system (Soil Survey Staff 1990).

In the present investigation, the control, N, P, K and NPK treatments were considered. The amounts of fertilizers applied are given in Table 1. Initially, N was applied as (NH₄)₂SO₄ and later on in the form of NH₄NO₃; P was applied as super phosphate until discontinuation in 1984; K was in the form of KCl. All fertilizers were broadcast before seedbed preparation, and for the NPK treatment, additional N has been top dressed since 1985. In this paper,

Table 1 Rates of N, P and K fertilizers (kg ha⁻¹) applied per season in the course of the experiment

Year	N	P	K
1939–1966	42.5	34	31.5
1967–1972	85	68	63
1973–1983	205	100	100
1984	205	0	100
1985–1999	125+125 ^a	0	80+100 ^b

^a Additional N top-dressed on NPK treatment

^b Additional K applied to NPK treatment

Table 2 Effect of direct N and K and residual P fertilizers on chemical properties^a of soil under long-term crop rotation. Means in columns followed by the same letter do not differ significantly

Treatment	pH(KCl) (1:2.5) ^b	TOC ^b	TN ^b	AP ^b	K ^{+c}	Ca ^{2+c}	Mg ^{2+c}	Na ^{+c}	Ca/Mg	Ca/K	Mg/K
Control	6.35a (0.03)	5841a (541)	591ab (30.8)	1.71b (0.22)	74c (2.56)	870a (19.9)	392a (18.6)	19ab (1.7)	2.2	11.8	5.3
N	5.79c (0.1)	4519bc (311)	581b (41.1)	2.08b (0.16)	67c (4.6)	674bc (33.8)	295b (7.84)	16ab (2.04)	2.3	10.1	4.4
P	6.13b (0.03)	3777c (230)	659ab (47.4)	76.8a (1.87)	34d (1.47)	648c (7.33)	261c (4.2)	19ab (2.99)	2.5	19.1	7.7
K	6.24ab (0.03)	4115c (71.6)	567b (27.1)	2.31b (0.24)	279a (3.84)	758b (62.6)	315b (8.27)	21a (1.11)	2.4	2.7	1.1
NPK	4.45d (0.1)	5549ab (410)	701a (21.7)	73.5a (2.79)	158b (4.25)	337d (22.0)	110d (1.49)	13b (2.33)	3.1	2.1	0.7
LSD _{0.05}	0.21	1059	105	4.56	10.7	104	30.0	6.4	–	–	–

^a All values except pH are in mg kg⁻¹

^b Mean of three determinations

^c Mean of two determinations

the N, P and K treatments are referred to as “simple fertilizer treatments” and the NPK treatment as “balanced fertilizer treatment”.

Maize (cv. Pioneer 6431) has been grown in summer rotated with field pea (cv. Swartbekkie) in winter. Plant population for maize is 55,000 plants ha⁻¹ in rows 910 mm apart. Seeding rate for field pea is 136 kg ha⁻¹. Fertilizers have been applied to maize only.

Soil samples were collected from the selected treatments at three sampling dates, viz: (1) October 1998 after harvesting field pea and before planting maize; (2) January 1999 at about the mid-growth stage of maize; and (3) July 1999 at about the mid-growth stage of field pea. Soil samples were taken from the top 200 mm at at least three random positions in each plot and samples from each plot were pooled and mixed. After sieving (<2 mm), approximately 250 g of each sample was stored at 5°C and subsequently used for microbiological assays. The remaining soil was air-dried for chemical analysis.

Soil chemical properties were determined according to standard procedures described in the Handbook of Standard Soil Testing Methods for Advisory Purposes (Soil Science Society of South Africa 1990) and Soil Sampling and Methods of Analysis (Canadian Society of Soil Science 1993). Soil microbial biomass C (SMB-C), N (SMB-N) and P (SMB-P) were estimated by the chloroform-fumigation-extraction methods (TSBF 1993). Enumeration of microbial populations was done by dilution plating using tryptic soy agar (Lawley et al. 1983) for bacteria, water-yeast extract agar (Crawford et al. 1993) for actinomycetes, and potato-dextrose agar supplemented with 50 µg rifampicin l⁻¹ for fungi. Plates were incubated at 28°C in the dark and counting was done after 7–10 days of incubation.

Data were subjected to statistical analysis with respect to main effects and sampling date using the general linear models procedure of the Statistical Analysis Systems. Variances between treatments were compared according to Duncan's multiple range test or Student's *t*-test. Correlation coefficients were determined for some selected soil properties and crop yield. Variations in chemical and microbial properties of the soil under maize (January 1999) and under field pea (July 1999) were compared to assess crop rotation effects. Long-term changes in some selected nutrient contents were computed on the basis of data from Steynberg (1986).

Results and discussion

TOC, TN and AP

TOC content of the control soil was significantly greater than that of the simple fertilizer treatments, but did not differ from the NPK plots (Table 2). These results are in

accordance with Duncan's multiple range test ($P=0.05$). Values in parentheses are SEMs. TOC Total organic C, TN total N, AP available P