Influence of soil nutrient management on the weed control efficacy of atrazine in maize

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Abstract

The improvement of soil nutrient status by appropriate fertilizer management practices may favour crops in the competition against weeds which have inherent mechanisms for effective nutrient mining from soils. Field experiments were conducted in 2011 (late season) and 2012 (early season) at the Teaching and Research Farm of Federal University of Technology, Akure, Nigeria to evaluate the influence of 350 kg ha^{-1} of NPK 20-10-10 fertilizer and neem seed-based fertilizer (NSBF) at various rates on the weed control efficacy of atrazine applied pre-emergence at the recommended rate of 3.0 kg a.i. ha^{-1}. The results show that NPK 20-10-10 combined with atrazine provided effective weed control which did not differ significantly ($P<0.05$) from NSBF whose efficacy was rate dependent in both years. Maize plant growth parameters increased in response to herbicide-fertilizer combinations which reflected in higher grain yields. The NSBF increased soil pH and organic matter and ensured the supply of needed nutrients as indicated by the levels after harvest compared to the NPK fertilizer and control treatments. The presence of NSBF conferred better efficacy on atrazine for weed control and this compatibility increased the competitive edge of field-grown maize.

Keywords: Maize, atrazine, neem seed-based fertilizer, weed control, efficacy

Introduction

The partitioning of available soil nutrients among the various species within a plant community is largely informed by the inherent ability of each species to compete for the nutrients. Weeds, as unwanted plants, naturally obtain more soil nutrients than crops due to certain inherent mechanisms they possess for effective nutrient mining (Moody, 1981). The role of nutrient management in weed control is critical because the interaction between weed behaviour and nutrient dynamics, though inconsistent, can be relevant in system sustainability (Bajwa *et al*., 2014). The responses of weeds to fertilizers are diverse and are determined by the rates and methods of application. The ability of weeds to be influenced in terms of nitrogen assimilation and growth determines their sensitivity to fertilizer application. Therefore, it is not sufficient to have information on the nutrient requirements for high yields, knowledge of fertilizer types and doses, placement methods and time of application which may place the crop at a better competitive pedestal against weeds may also be very important.

Many crops in the early stages of establishment are poor competitors against weeds because of slow growth rate and limited root ramification and leaf area development (Patel *et al*., 2006). Hence, weeds adversely affect the growth, yield and quality of crops by inducing depletion of soil nutrients and moisture as well as competing with the crops for space and sunlight (Patel *et al*., 2006). Maize (*Zea mays* L) plants are particularly exposed to and susceptible to weed competition during the early stages of growth in the first few weeks after sowing (Evans *et al*., 2003; Marshall, 2004). The most effective method of weed control in maize fields is the use of herbicides (Idziak and Woznica, 2013) and atrazine (2-Chloro-4-ethylamine-6-isopropylamine-s-triazine) which combines ready availability with cheapness and effectiveness over the years has been widely adopted by farmers in southwestern Nigeria (Aladesanwa, 2005). However, the sole dependence on atrazine for weed control in maize has given less satisfactory results in recent times because of its being effective against dicotyledonous broad-leaved weeds and failure to provide season-long weed control (Aladesanwa and Adejoro, 2009). This has been attributed to enhanced degradation of atrazine in soils (Workman *et al*., 1995) which makes the search for farm cultural practices that can complement the herbicide action against weeds an imperative.

Tillage, weed management and fertilizer application to increase soil nutrient supply are crop production practices which influence weeds in agriculture (Barberi *et al*., 1997). Out of these cultural practices, the influence of soil fertility management is the least understood as it can complement or sabotage the effectiveness of herbicides. The objective of this study was to evaluate the effects of varying rates of a commercial neem seed-based fertilizer and the field rate of atrazine on weed control efficacy as well as growth and yield performances of maize in southwest Nigeria.

Materials and Methods

Two field experiments were conducted at the Experiment Station of the Department of Crop, Soil and Pest Management on the Teaching and Research Farm, Federal University of Technology, Akure in 2011 late season and 2012 early season. The Experiment Station (7º16′N, 5º12′E) is located in the rainforest zone and experiences sub-humid tropical climate with average annual rainfall of 1,300 mm and mean temperature of 27ºC.

A fairly level portion of land (450 m^2) was marked out and divided into 5×4 m plots separated by 1 m paths. The topsoil (0-15 cm) samples were randomly taken and bulked into a composite in each year for analysis. The soil in both years was sandy clay loam with pH (H_2O) of 5.5 and 5.7, 18.2 and 17.0 g kg^{-1} organic carbon, 1.5 and 1.58 g kg^{-1} total nitrogen, 10.8 and 11.2 mg kg^{-1} available phosphorus and 0.42 and 0.48 cmol kg^{-1} exchangeable potassium in 2011 and 2012 respectively. Two seeds of Downy mildew resistant (DMR) maize variety were sown at 75×25 cm spacing but later thinned to one seedling stand^{-1} at 2 weeks after planting. The treatments applied were atrazine at the recommended field rate of 3.0 kg a.i. ha^{-1} in combination with 0, 100, 200 and 300 kg ha^{-1} of neem seed-based fertilizer (denoted as N0/ATR, N100/ATR, N200/ATR and N300/ATR respectively). The treatments included atrazine combined with NPK 20-10-10 applied at 350 kg ha^{-1} (denoted as NPK/ATR) to serve as the standard practice and a control (no fertilizer and herbicide, NF/WC) in three replicates and arranged as a randomized complete block design. Atrazine (80 WP), a wettable powder formulation, was applied to maize pre-emergence with a knapsack sprayer fitted with Polijet nozzles calibrated to deliver 250 l ha^{-1} of spray solution at a pressure of 2.5 kg cm^{-2}. The neem seed-based fertilizer was a commercial formulation of neem seed cake blended with mineral fertilizer (Royal Fertilizer Plus®) containing NPK 7-7-7. The fertilizer was placed as sub-surface band to maize seedlings at 2 WAP.

Weed samples were obtained randomly at 4 using 50×50 cm quadrats at two sites within each plot. The weed samples collected were separated by species, counted, oven-dried at 80ºC for 48 hours and weighed. At harvest (12 WAP), all the plots were cleanweeded and the weeds weighed to allow for comparison of total weed growth from time of sowing till harvest among the different treatments and determine the weed control efficacy of the herbicide. Maize growth data (plant height and number of leaves) were determined at 4, 6, 8 and 12 WAP from 10 randomly selected and tagged plants in each plot while leaf area was measured at harvest. At 12 WAP, dry maize cobs were harvested from 10 randomly selected stands in each plot, dehusked and shelled. The grains were weighed and the yield was adjusted to 13% moisture content. After harvest, soil (0-15 cm) samples were taken randomly from each plot, bulked for a composite. The samples were air-dried, sieved (<2 mm) and analyzed for pH (H_2O), organic carbon, total nitrogen, available phosphorus and exchangeable potassium, calcium and magnesium using the procedures described in Udo *et al*., 2009).

Data of growth measurements, weed dry weights and maize grain yield and soil properties were subjected to analysis of variance. The treatment means were compared using the Tukey test.

Results

The effects of different rates of neem seed-based fertilizer combined with atrazine on weed dry weight and weed control efficacy are shown in Table 1. At 4 WAP, atrazine significantly ($P<0.05$) reduced the dry weight of weeds compared to the control treatment in both years. The least weed dry weight was obtained with the standard practice (NPK/ATR) while the increase in rate of neem seed-based fertilizer caused reduction in weed dry weights.

Table 1: Effects of fertilizer-atrazine treatments on weed dry weight (g) and weed control efficacy (WCE)

	2011				2012			
Treatments	Weed dry weight		Weed control efficacy		Weed dry weight		Weed control efficacy	
	4WAP	12 WAP	4WAP	12 WAP	4WAP	12 WAP	4WAP	12 WAP
N0/ATR	105.3^{b}	297.9^{b}	37.7^{c}	38.7^{b}	113.3^{b}	284.4^{b}	26.7^{b}	45.9^{c}
N100/ATR	100.7^{bc}	232.5^{bc}	40.4^{bc}	51.9^{a}	102.3^{bc}	261.9^{b}	34.0^{ab}	50.0^{c}
N200/ATR	81.7^{cd}	218.9^{c}	51.7^{ab}	55.0^{a}	112.3^{b}	245.7^{b}	27.6^{b}	53.2^{bc}
N300/ATR	72.0^{d}	193.7^{c}	57.4^{a}	60.1^{a}	100.0^{bc}	184.4^{c}	35.3^{ab}	65.0^{ab}
NPK/ATR	70.0^{d}	194.9^{c}	58.6^{a}	59.7^{a}	90.7^{c}	159.1^{c}	41.4^{a}	69.7^{a}
N0/WC	169.0^{a}	486.4^{a}	0.0^{d}	0.0^{c}	155.0^{a}	527.2^{a}	0.0^{c}	0.0^{d}
S.E.	4.23	15.1	2.59	2.45	3.72	10.8	2.39	2.48

Means in a column that do not share a letter are significantly different.

In both years, N300/ATR gave the least weed dry weights but did not differ significantly from NPK/ATR and N200/ATR. The same trend was observed at harvest (12 WAP) but weed weights were generally higher than at 4 WAP in both years. The weed control efficacy (WCE) was boosted by NPK and NSBF at the 4 and 12 WAP in both years. In 2011, the highest WCE from NPK/ATR did not differ significantly from N200/ATR and N300/ATR at 4 and 12 WAP while in 2012, the values between NPK/ATR and N300/ATR were similar. Thus, the NPK/ATR treatment gave the highest WCE but in the case of NSBF, the WCE increased with the higher rates.

The maize plant height was least in the control at 4 WAP in 2011 while the tallest plants obtained from NPK/ATR did not differ from the other treatments (Table 2). The plant height increased in response to fertilizer application at 6 WAP and the trend continued till 12 WAP. The tallest plants produced in NPK/ATR treatment had heights similar to N300/ATR at 6 WAP and the other treatments that did not differ among themselves at 8 and 12 WAP while the control (NF/WC) and N0/ATR had the same least plant height.

Table 2: Effects of fertilizer-atrazine treatments on maize plant height (cm)

Treatments	2011 Weeks after planting				2012 Weeks after planting			
	4	6	8	12	4	6	8	12
N0/ATR	70.8^{a}	87.1^{cd}	147.0^{ab}	154.6^{ab}	62.2^{ab}	74.6^{a}	115.9^{bc}	169.7^{c}
N100/ATR	61.6^{ab}	108.0^{abc}	151.3^{ab}	170.0^{a}	64.2^{ab}	82.0^{a}	136.2^{abc}	187.2^{c}
N200/ATR	67.3 ^{a}	100.1^{bcd}	164.8^{a}	198.7^{a}	66.5^{a}	83.9^{a}	141.1^{ab}	194.2^{abc}
N300/ATR	64.4^{ab}	113.2^{ab}	165.7^{a}	200.3^{a}	55.3^{ab}	94.1^{a}	170.4^{ab}	202.5^{ab}
NPK/ATR	72.2^{a}	128.0^{a}	195.3^{a}	221.7^{a}	73.6^{a}	94.6^{a}	179.8^{a}	219.1^{a}
NF/WC	48.2^{b}	83.4^{d}	89.7^{b}	95.5^{b}	42.4^{b}	60.2^{a}	84.7^{c}	108.3^{d}
S.E.	3.59	4.03	14.0	10.2	4.2	6.9	10.7	5.45

Means in a column that do not share a letter are significantly different.

The same trend was obtained in 2012 with the tallest plants produced in NPK/ATR which did not differ significantly from the other treatments at 4 and 6 WAP but the difference was significant from N0/ATR and NF/WC at 8 and 12 WAP. The maize plant height increased with NSBF application rates at all sampling periods in both years but the plants at N300/ATR differed significantly only from N100/ATR at 12 WAP of 2012.

The number of leaves plant^{-1} increased in a response to the fertilizer-atrazine combination over the sampling period in both years (Table 3). The least values were obtained in the control (NF/WC) treatments while the highest values in NPK/ATR and N300/ATR were similar and did not differ from the other treatments. However, the increase in number of leaves plant^{-1} from NSBF/ATR application was in a rate-dependent manner. Leaf area plant^{-1} increased significantly with the application of fertilizer-atrazine combination compared to the control which gave the least values in both years. The NPK/ATR treatment gave highest leaf area in 2011 which differed significantly from the other treatments that were similar while N200/ATR and N300/ATR were similar to NPK/ATR in 2012.

Table 3: Effects of fertilizer-atrazine treatments on the number of leaves and leaf area of maize

Treatments	2011 Weeks after planting					2012 Weeks after planting				
	4	6	8	12	Leaf area	4	6	8	12	Leaf area
N0/ATR	7.8^{ab}	10.4^{a}	11.4^{a}	11.5^{ab}	304.5^{b}	8.2^{a}	9.8^{ab}	9.8^{ab}	9.9^{ab}	268.8^{b}
N100/ATR	7.2^{ab}	10.0^{a}	11.1^{a}	12.0^{a}	309.8^{b}	7.1^{ab}	7.9^{bc}	9.6^{ab}	10.9^{ab}	272.9^{b}
N200/ATR	7.9^{ab}	9.7^{a}	11.2^{a}	12.0^{a}	318.0^{b}	6.5^{ab}	9.1^{abc}	10.8^{a}	12.8^{a}	336.8^{ab}
N300/ATR	6.5^{b}	10.3^{a}	12.5^{a}	12.9^{a}	325.5^{b}	6.6^{ab}	10.2^{ab}	10.7^{a}	12.9^{a}	350.3^{ab}
NPK/ATR	8.5^{a}	10.0^{a}	12.3^{a}	12.7^{a}	474.0^{a}	7.4^{ab}	10.9^{a}	12.7^{a}	12.9^{a}	405.8^{a}
NF/WC	6.6^{b}	7.2^{b}	8.7^{a}	9.3^{b}	180.0^{c}	5.8^{b}	6.2^{c}	6.5^{b}	7.6^{b}	102.5^{c}
S.E.	0.34	0.44	0.74	0.49	23.0	0.38	0.57	0.72	0.74	19.5

Means in a column that do not share a letter are significantly different.

The effects of fertilizer-atrazine combination on the grain yield of maize in the two years are shown in Fig. 1. The maize grain yields are higher in 2011 than 2012 but followed the same trend in responses to the treatments. The maize grain yields were significantly higher in fertilizer-atrazine combination treatments than the control and with the best performance from NPK/ATR. The maize yield increase with the application of NSBF was rate-dependent in both years but none of the treatments was significantly higher than N0/ATR in 2011.

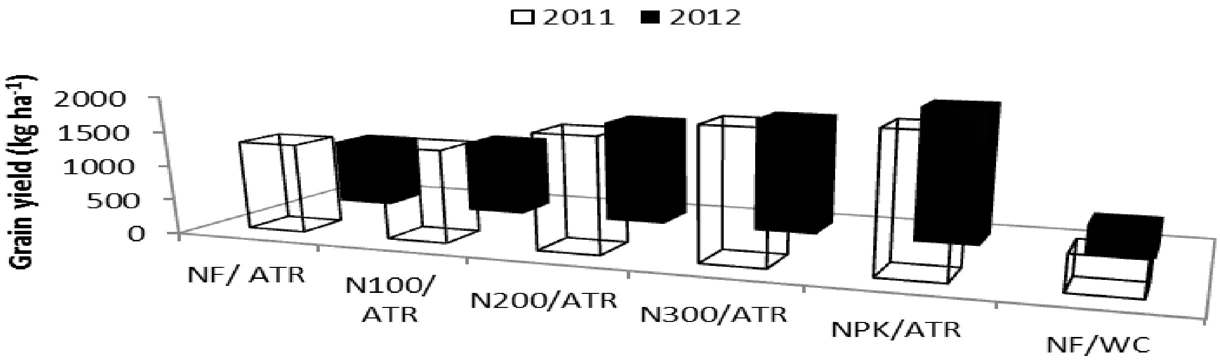

Fig 1. Effects of Fertilizer-atrazine treatments on maize grain yield (kg ha^{-1})

Table 4 shows the effects of fertilizer-atrazine combination on soil properties after cropping in 2011 late season and 2012 early season. The NPK/ATR treatment lowered soil pH compared to NSBF whose addition caused increase in soil pH with increasing rate to the highest value at N300/ATR. Organic matter and total nitrogen decreased significantly in the NPK/ATR treatment compared to NSBF whose highest values obtained in N200/ATR and N300/ATR were similar. Available P increased with the applied NSBF to the highest value at N300/ATR which differed significantly from the lower rates and NPK/ATR that, in turn, was not different from N200/ATR and N100/ATR. The exchangeable cations were lower in NPK/ATR compared to NSBF treatments which gave the highest exchangeable K in N300/ATR that differed from other treatments while the exchangeable Ca and Mg did not differ significantly among the treatments. In 2012, soil pH did not differ among all the treatments while organic matter, total N and available P increased with the application of NSBF to the highest values at N300/ATR which differed significantly from the lower rates and NPK/ATR. The exchangeable K, Ca and Mg also decreased in NPK/ATR treatment compared to N200/ATR and N300/ATR which gave the highest similar values.

Table 4(a). Effects of fertilizer and atrazine treatments on soil nutrients and pH at maize harvest in 2011

TREATMENTS	Soil pH (1:2 H_2O)	Organic matter (%)	N (%)	P (mg/kg)	K (cmol/kg)	Mg (cmol/kg)	Ca (cmol/kg)
NF/ WC	5.13^{bc}	1.10^{b}	0.13^{d}	7.93^{bc}	0.42^{b}	1.13^{a}	2.30^{b}
N0/ ATR	5.03^{bc}	1.09^{b}	0.17^{bc}	4.82^{d}	0.36^{bc}	1.20^{ab}	2.90^{a}
N100/ ATR	5.23^{abc}	1.09^{ab}	0.1^{6c}	7.00^{c}	0.39^{bc}	1.30^{a}	2.90^{a}

N200/ATR	5.57[ab]	1.13[ab]	0.19[ab]	9.02[b]	0.42[b]	1.30[a]	3.10[a]
N300/ATR	5.92[a]	1.15[a]	0.21[a]	11.82[a]	0.50[a]	1.30[a]	3.20[a]
NPK/ATR	4.64[c]	0.96[b]	0.12[d]	8.24[bc]	0.33[c]	1.00[b]	2.40[b]
se	0.16	0.03	0.004	0.28	0.01	0.04	0.09

Means in a column that do not share a letter are significantly different.

Table 4(b). Effects of fertilizer and atrazine treatments on soil nutrients and pH at maize harvest in 2012

TREATMENTS	Soil pH (1:2 H_2O)	Organic Matter (%)	N (%)	P (mg/kg)	K (cmol/kg)	Mg (cmol/kg)	Ca (cmol/kg)
NF/WC	5.46[a]	1.10[bc]	0.15[c]	7.31[d]	0.20[d]	1.20[a]	2.00[c]
N0/ ATR	5.75[a]	0.86[d]	0.11[d]	7.86[cd]	0.30[bc]	1.00[b]	2.30[bc]
N100/ ATR	5.41[a]	0.92[cd]	0.18[c]	8.94[bc]	0.34[ab]	1.00[b]	2.50[b]
N200/ATR	5.76[a]	1.17[b]	0.22[b]	10.27[b]	0.37[a]	1.20[a]	2.40[b]
N300/ATR	5.77[a]	1.61[a]	0.32[a]	11.90[a]	0.36[a]	1.20[a]	3.00[a]
NPK/ATR	5.64[a]	1.09[bc]	0.16[c]	6.69[d]	0.25[c]	0.90[b]	2.00[c]
SE	0.17	0.04	0.006	0.28	0.009	0.03	0.07

Means in a column that do not share a letter are significantly different.

The residual fertility status of the soils as related to the rate of NSBF application was subjected to regression analysis. Table 5 shows that soil pH, organic matter, total N, available P exchangeable K, Mg and Ca had near-perfect to perfect correlation with rates of NSBF in combination with atrazine in 2011. Available P, organic matter and total N had perfect correlation with rates of NSBF while the coefficients were lower for soil pH, exchangeable Mg, Ca and K in 2012.

Table 5. Linear correlation and regression analysis between increasing dose of NSBF (X) and soil pH or nutrient content (Y) at maize harvest (n=3)

	Late 2011		Early 2012	
Soil parameter	R	Regression equation	R	Regression equation
Soil pH(1:2 H_2O)	+1.00	Y= 0.35x+4.9	+0.88	Y=0.18x+5.29
Organic matter (%)	+0.98	Y= 0.03x+1.01	+0.99	Y=0.35x+0.54
N (%)	+0.95	Y= 0.05x+0.08	+0.97	Y=0.07x+0.1
P (mg/kg)	+1.00	Y= 2.41x+4.46	+1.00	Y=1.48x+7.41
K (cmol/kg)	+0.97	Y= 0.06X+0.33	+0.65	Y=0.01x+0.34
Mg (cmol/kg)	+0.87	Y= 0.05x+1.23	+0.87	Y=0.1x+0.93
Ca (cmol/kg)	+0.98	Y= 0.15x+2.77	+0.78	Y=0.25x+2.13

R = Correlation coefficient

Discussion

The significant differences in weed dry weight observed in the fertilizer-atrazine treatments compared to the control at 4 and 12 WAP indicate that the pre-emergence herbicide was effective in shielding the maize crop against early weed competition. Weed weight decreased in the order of increasing dose of NSBF probably in relation to the higher quantities of available nutrients needed to support vegetative growth in maize and so engender better weed suppression. This reduction in weed dry weights is a manifestation of the direct relationship of weed control efficacy with increasing dose of NSBF at both sampling periods. Fertilizer levels, especially N, can alter crop-weed interactions significantly in terms of inhibition and promotion (Cathcart and Swanton, 2003). Weed performance can be greatly influenced by fertilizer regimes (Bajwa *et al*., 2014) because the manipulation of fertilizer strategies which reduces the extra nutrients not taken up by the crops decreases weed interference in crops (Di Tomaso, 1995). The management practices responsible for the contribution of fertilizer application to weed suppression and modify the weed crop competition are varying the rates (Cathcart and Swanton, 2003), timing of application (Blackshaw *et al*., 2004) and methods of placement (Mesbah and Miller, 1999). The sub-surface banding of N and P fertilizers which reduced the uptake by weeds was a more suitable placement method than broadcasting (Mahler, 2001; Blackshaw, 2005; Blackshaw and Molner, 2009).

The weed weights at harvest (12 WAP) were high which show that the atrazine-fertilizer combinations were less effective with time and failed to provide season-long control of the weeds. Aladesanwa and Adejoro (2009) had observed that one of the limitations to atrazine use is the failure of the various rates to provide season-long weed control in maize compared to the untreated plots.

The higher maize grain yields in atrazine-fertilizer combinations than the control treatment indicate that it is necessary to supply extra nutrients from fertilizer and protect the crop from weed competition. The nutrients supplied by NPK and NSBF and the differential weed growth among the treatments and compared to the control were reflected in the significant maize yield responses. The highest grain yield obtained in NPK/ATR is related to the ready supply of nutrients from the mineral fertilizer which contains more nutrients (NPK 20-10-10) than NSBF irrespective of the application rates. The composition of NSBF at NPK 7-7-7 and nutrients derived from inorganic and organic sources mean low amounts of available nutrients and slow supply rate because of the time required for mineralization of the organic nutrients. Besides, the highest rate of NSBF at 300 kg ha^{-1} will only supply 21 kg N ha^{-1} whereas 60-120 kg N ha^{-1} is recommended for maize in low-medium fertility soils in Nigeria (FFD, 2002).

The application of NPK fertilizer raised soil acidity in line with previous reports on the acidifying effects of mineral fertilizers (Brady and Weil, 2008; Adepetu *et al*., 2014). The ammonium ions in N-containing fertilizers are oxidized to nitrates through acid-forming reactions modified by soil microbial population. On the other hand, soil pH increased in plots to which NSBF was applied indicating that it possesses liming properties. This is a feature of organic manures which reflected in the higher status of exchangeable cations compared to the NPK and control treatments. Also, the NSBF inhibits nitrification thereby regulating the amount of N made available to plants by reason of slow-release process that prevents nitrate leaching and whose contribution to soil acidity is widely known (Lehmann and Schroth, 2003).

This study has shown that neem seed-based fertilizer applied at the appropriate rate, time and method can be combined with time-tested herbicide- atrazine- to put maize on a higher competitive pedestal above weeds in the field. The ready supply of nutrients needed for vegetative development and the weed suppression caused by the two factors ensured better growth which culminated in high maize grain yields that compared favourably to mineral fertilizer (NPK 20-10-10). The neem seed-based fertilizer had high residual effects on soil fertility indices compared to NPK fertilizer.

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