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Research article

Effect of Pyrite (FeS_2) Application Rates on Sodic soils and Performance of Maize (*Zea-mays*) Plants

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ABSRACT

A pot experiment was carried out between the months of April and June, 2013 in order to determine the effects of pyrite application rates on the performance of maize grown on sodic soils sampled from Baga, Kukawa LGA, Borno state. The study was carried out at the Screen House of the Faculty of Agriculture, University of Maiduguri. The experiment consisted of 4 levels of pyrite (0.0, 12.5, 25.0 and 37.5 t/ha, equivalent to 0.0, 2.5, 5.0 and 7.5 g/3kg soil), and replicated thrice. Maize seeds were sown to the treated pots and harvested at 8 WAP. Parameters measured include plant height, shoot, root, and total dry matter weights. Soil chemical properties such as pH, EC, OC N, P, K, Na, Ca, Mg, SAR and ESP were determined after harvest. The results indicated that all the chemical properties, except Ca and Mg decreased significantly ($P<0.05$) with increase in pyrite application rates, while maize growth significantly ($P<0.05$) increased in proportion to the pyrite applications. It could be concluded that, incorporation of pyrite at the rate of 7.5 g/3kg soil (37.5 t/ha pyrite) in the soil top layer with adequate leaching is recommended for sustainable maize production in the study area. Determination of maximum pyrite application rate(s) that could completely reclaim the sodic soils of Baga area remains a challenge for future research works.

Key words: Pyrite application rates, Sodicity, Leaching, Maize, Performance, Baga-Nigeria

Introduction

Soil sodification is regarded as a major threat to irrigated agriculture as well as a major concern to most farming communities around the globe. Sodicity contributes to soil degradation and there exist a great need for its amelioration and/or reclamation (Lal, 2001). Sodicity problems are alarmingly dominant in arid and semi arid areas, with poor drainage, high water table, and weathered materials that haven't leached properly, and which requires prompt attention. Soils are indispensible resources that have been exploited for thousands of years by man for several purposes resulting in their degradation (Easwaran *et al*., 2001; Junge and Skowronek, 2007). When soils with sodicity problems are not properly managed or reclaimed, it can lead to potential problems such as total loss of soil structure, water stress, accumulation of Na, Mo, and B in toxic amounts, and immobilization of certain nutrients that causes poor yield of crops (Ogunwale *et al*., 2001). The problem also occurs in irrigation water containing high sodium salts with sodium adsorption ratio (SAR) greater than 13 (Alperovitch *et al*., 1985; Armstrong, 1989; Arunin, 1997). Pyrite is one of the chemicals used in reclaiming sodic soils. The acidifying property of pyrite (FeS_2) lowers the pH of a soil to near neutral levels, and it is a potentially cheap fertilizer, serving as a source of sulfur (S) and iron (Fe) in the soil for both plant uptake and microbial use.

The challenge with the use of pyrite however, is that in many experiments, pyrite applied to sodic soils were out performed by other sulfur bearing minerals such as gypsum ($CaSO_4$). Gupta *et al*. (1988) added that, this had led to the low level of acceptance of pyrite as a soil amendment compared to gypsum. Also, Verma and Abrol (1980) reported that pyrite seem to be only ¼ times as effective as gypsum, when their effects on soil properties and the yield of wheat and rice were assessed. The lack of information in the use of pyrite in the study area to amend soil sodicity caused by excessive accumulation of sodium ions necessitated this work. This study therefore, is aimed at assessing the effect of pyrite application rates on soil chemical properties and performance of Maize grown on sodic soils at Baga area of Borno state.

Materials and Methods

Experimental site and location

A pot experiment was carried out at the Faculty of Agriculture Screen House, University of Maiduguri between the months of April and June, 2013 in order to examine the effects of application rates of pyrite on the amendment of sodic soil sourced from Baga LGA, Borno state, located between longitude 12.63^{o}N and latitude 13.85^{o}S. Maiduguri is situated in the north-eastern part of Nigeria with a semi-arid agro-ecology, having long term mean annual rainfall of 553 mm and a very hot dry climate. Rainfall is unimodal, starting on average in mid-June to end of September (Grema and Hess, 1994).

Soil sample collection and preparation

Composite soil samples were collected from Baga in Kukawa LGA of Borno state. The soils were tested in the laboratory for some physico-chemical properties. The soil samples were collected at 0-15 cm depths, and later weighed into 12 experimental pots, which received 3 kg of soil each. The soils were air-dried, crushed and labeled in polyethene bags before laboratory determinations as suggested by Rayar (1983).

Experimental design and treatments

The experiment was laid out in a completely randomized design (CRD) with 4 treatment levels and replicated 3 times. Treatment 1 (control) received zero rate of pyrite, while treatment 2, 3, and 4 received 2.5, 5.0, and 7.5 g of pyrite per pot (3 kg soil), respectively. Each pot was then leached with water in excess of the calculated field capacity of 37.5 cm^3 of water per 3 kg of soil (12.5 cm^3/1kg of soil).

Cultural practices

Sowing and thinning

Before planting, seed viability test was carried out by putting maize seeds into water for 24 hours to observe those suspended and those that sank. The suspension indicates seeds not viable while sinking indicates viable seeds. Sowing was done on the 25th of April, 2013 in the plastic pots and were treated with 4 levels of pyrite (T_1, T_2, T_3 and T_4), before leaching was done. Thinning was done at 2 weeks after planting (WAP) to leave just 2 maize stands per pot in order to ensure adequate spacing. Leaching was done 3 times a week, while in the event of any weed occurrence; hand picking was done to remove weeds in the pots.

Data collection on plant parameters

Harvesting and collection of plant parts

Harvesting was done using a knife to cut the stem from the base of the shoots. The stem and leaves were harvested together and weighed after drying in order to obtain dry matter weight. The roots was carefully uprooted, followed by washing to remove the soil particles from the shoots and roots, before drying and weighing in order to obtain the root dry weights.

Determination of Plant height

Plant height was measured using a meter tape at 2, 3, 5 and 7 WAP, respectively.

Determination of root, shoot and total dry matter contents

The root dry matter (RDM) and shoot dry matter (SDM) weights were obtained by sun-drying after harvesting and then oven dried at 65^0C for 24 hours in order to remove moisture from the plant materials, before being weighed using a weighing balance. The total dry matter (TDM) was then obtained by summing up the values of RDM and SDM.

Soil analysis

The soil physico-chemical properties such as particle size distribution was carried out using the hydrometer method, while soil organic carbon (OC) was determined by wet dichromate oxidation method. The OC was converted into organic matter (OM) by multiplying it by a factor of 1.724. The total nitrogen (N) was determined using micro-kjeldahl approach and available phosphorus (P) by molybdenum blue colorimeter method, after Bray-1 extraction. The exchangeable cations were extracted with ammonium acetate, after which potassium (K) was determined by flame photometer, while calcium (Ca) and magnesium (Mg) were determined by EDTA titration method. Soil pH was also determined in a 1:2.5 soil-water suspension using a pH meter (Tel and Hagarty, 1984). Both exchangeable sodium percent (ESP) and SAR were computed in accordance with Tel and Hagarty (1984) procedure, expressed as:

$$SAR = [Na^+] / \sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}$$, and

$$ESP = \frac{exchangeable\ sodium\ (meq/100gsoil)}{cation\ exchange\ capacity\ (meq/100gsoil)} \times 100$$

Statistical analysis

The data collected were subjected to analysis of variance (ANOVA). Differences between the means were separated using standard error (SE±) at 5% level of probability (Mead and Curnow, 1983).

Results and Discussion

Physico-chemical properties of soil of the study area

The results of the physico-chemical properties of the soils, before treatment applications are presented in Table 1**.** The results revealed that the soil reaction (pH) was 9.5, which was strongly alkaline (sodic) in nature. The observed high soil pH was perhaps due to the presence of exchangeable Na ions on the exchange surfaces of the soils as reported by Agarwal and Yadav (2002). The low concentration of Ca and Mg was probably still due to the high exchangeable Na ions at the soil surfaces, which likely dispersed the Ca and Mg ions away from the exchange surfaces, that resulted in their low concentrations (Abrol *et al*., 2000). The soil had an electrical conductivity (EC) of 800 μScm^{-1}, which was relatively high, and with low concentrations of Ca and Mg. On the other hand, Na, K, SAR, ESP, O.M, and N contents of the soils were also high. The high OM and N contents could be attributed to the dense vegetation, which are leguminous such as acacia trees that perhaps fixed more N content into the soils.

Effects of pyrite application rates on maize heights

The results of the effect of pyrite application rates on maize heights at 1, 3, 5, and 7 WAP are presented in Table 2. The results indicated that the tallest plants (5.73cm) were recorded with treatment 7.5 g application rate, at 1 WAP, while the shortest plants were observed in the control treatment. The plant heights were not significantly (P>0.05) different at 1 WAP, compared to heights observed at 3, 5 and 7 WAP, which showed significant (P<0.05) difference between the treatments. For instance, at 5 WAP, all plant heights showed significant differences (P<0.05) from plants treated with 7.5 g, where the tallest plant (24.90 cm) was observed. Generally, the results exhibited significant (P<0.05) differences among the treatments at 7 WAP. The highest value of plant height (26.10 cm) was observed under 7.5 g treatment applications in this study.

The significant variations observed at 3, 5, and 7 WAP might have been due to the presence of sulfur absorbed by the plants and which perhaps increased the plant heights. This agrees with the findings of Tiwari *et al*, (1999) who reported that pyrite may act as a fertilizer, when applied to sodic soils.

Effects of pyrite application rates on RDM, SDM and TDM

The results of effects of pyrite application rates on RDM, SDM and TDM are shown in Table 3. The results revealed that there was no significant (P>0.05) differences among the treatments in terms of RDM, SDM and TDM. Results indicated that the control treatment had the highest RDM with a mean weight of 3.27 g, while the least RDM of 2.63 g was obtained with 5 g pyrite application rate. Similarly, the control treatment still had the highest value of 7.77 g and 11.03 g in respect of SDM and TDM, while plants treated with 5 g of pyrite recorded the least estimates of 5.10 and 7.73 g in respect of SDM and TDM contents. The widely observed significant (P<0.05) differences among the treatments in terms of RDM, SDM and TDM was suggestive of negligible effects of pyrite applications on maize performance in the study area. This result closely compares with those obtained with 7.5 g of pyrite application rate earlier reported by Tiwari *et al*. (1999), which revealed that pyrite could be used as a fertilizing material, though its effect on dry matter weights may not correspond with increase in pyrite application rates. This implies that the more the pyrite application rates, the less the dry matter weights of the maize plants.

Effect of pyrite application rates on soil physico-chemical properties after treatments

The results of effects of pyrite application rates on the physico-chemical properties of the soils after treatment applications are presented in Table 4**.** The results revealed that the soil pH, and EC decreased significantly (P<0.05) with increase in pyrite application rates. The control treatment had the highest pH value of 8.57 compared to plants treated with 7.5 g of pyrite, which had a near neutral soil reaction (pH 7.03). Similarly, the highest EC value (724.60 µScm^{-1}) was obtained in the control experiment, while the least EC (675 µScm^{-1}) was recorded in pots treated with 7.5 g of pyrite application rate. In a similar pattern, the OM exhibited significant ($P<0.05$) variations among the treatments, although there was no significant ($P<0.05$) differences in OM contents between control and pots treated with 2.5 g of pyrite. Also, the OM decreased with increased pyrite applications, which showed that the plants utilized more OM under the influence of pyrite applications. This perhaps suggests that pyrite is a good fertilizing material as reported by Tiwari *et al*. (1999).

The Na content decreased significantly with increasing application rates. The control treatment had 6.92 meq/100g of soil, while the least Na value of 3.60 meq/100g was obtained with 7.5 g treatment. There was no significant ($P>0.05$) difference in Na contents from pots treated with 2.5 and 5 g of pyrite applications. Likewise, Ca and Mg both increased in control treatment than with the 7.5 g treatment. The lowest Ca and Mg contents of 2.35 and 1.64 meq/100g of soil were both obtained in the control treatment, while their highest values of 8.50 and 3.15 meq/100g were recorded with 7.5 g of pyrite application rate. These results are comparable with the findings of Gupta *et al*. (1988), who stated that both Ca and Mg counteract the effect of excess Na. It can be deduced from Table 4, that the pH, O.M, Na, K, and N all decreased as pyrite application rates increased, except for Ca and Mg both increased. This result concurs with the report of Gupta *et al*. (1988), who mentioned that the pyrite applied to sodic soils was out performed by another sulfur-bearing mineral. Gypsum ($CaSO_4$) as a source of Ca and Mg significantly ($P<0.05$) countered the effects of Na as expected. Both SAR and ESP values were also higher in the control treatment. The highest SAR was 12.8 and ESP was 15.06%, while the lowest SAR was 9.98 and the least ESP was 13.12 in this study.

Conclusion and Recommendations

The study revealed that the soils in Baga, Kukawa LGA is sodic in nature. Pyrite significantly ($P<0.05$) decreased the soil pH from 9.5 to a near neutral point (pH 7.03) with application rate of 7.5g/3kg of soil. Properties such as SAR, ESP, EC and Na contents significantly decreased with increase in pyrite applications, while Ca and Mg contents increased, following decline in Na content in the soils. Therefore, incorporation of pyrite at the rate of 7.5g/3kg soil (37.5 t/ha pyrite) into the top soil layer with adequate leaching should be adopted for sustainable production of maize in the study area. It is recommended that, further studies should focus on ascertaining the maximum rates of pyrite required to completely reclaim the sodic soils of Baga area.

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Table1: Physico-chemical properties of the soils before treatment application

Soil property	**Unit**	**Value**
Soil reaction (pH (1:2.5 soil-water))		9.5
Electrical Conductivity (EC)	μScm^{-1}	800
Organic Matter (OM)	%	3.80
Nitrogen (N)	%	0.36
Sodium (Na)	meq/100g soil	12.02
Calcium (Ca)	meq/100g soil	2.20
Magnesium (Mg)	meq/100g soil	1.40
Potassium (K)	meq/100g soil	2.32
Sodium adsorption ratio (SAR)	%	13.43
ESP	%	16.05

Table2: Effects of pyrite application rates on maize height (cm)

Treatment level (FeS_2 g)	**Plant heights at week(s) after planting (WAP)**			
	1_{wk}	**3_{wk}**	**5_{wk}**	**7_{wk}**
0 (control)	4.57	9.27	17.80	26.70
2.5	5.00	10.50	20.17	24.80
5.0	5.53	10.50	20.90	23.37
7.5	5.73	12.93	24.90	26.16
SE(±)	0.185	0.17	0.21	0.33

Key: $_{wk}$ = week

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Table 3: Effects of pyrite application rates on RDM, SDM and TDM

Treatment level (FeS_2 g)	**RDM**	**SDM**	**TDM**
0 (control)	3.27	7.77	11.03
2.5	2.97	6.50	9.47
5.0	2.63	5.10	7.73
7.5	2.77	6.83	9.60
SE(±)	0.20	1.16	1.15

RDM= Root dry matter, SDM= Shoot dry matter, TDM= Total dry matter.

Table 4: Effect of pyrite application rates on soil physico-chemical properties after treatment applications

Treatment level	**Soil property**									
(FeS_2 g)	pH	EC	OM	Na	Ca	Mg	K	ESP	SAR	N
0 (Control)	8.6	724.7	3.54	6.92	2.35	1.64	1.75	15.06	12.68	0.33
2.5	8.1	702.7	3.49	5.29	5.49	2.00	1.25	13.96	12.01	0.29
5.0	7.1	691.1	2.76	4.79	7.20	2.65	0.76	13.81	11.11	0.26
7.5	7.0	675.0	1.75	3.60	8.50	3.15	0.47	13.12	9.98	1.98
SE(±)	0.1	3.48	0.06	0.25	0.15	0.06	0.20	0.06	0.06	0.02

