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A LITERATURE REVIEW OF SOIL FERTILITY IN THE WEST AFRICAN SEMI-ARID TROPICS (WASAT)

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I. INTRODUCTION

Maintenance and improvement of soil fertility in WASAT agriculture has long been associated with soil organic matter content and bush-fallow rotation systems (53, 68). Increasing population pressure has forced many farmers to decrease, if not eliminate, fallow periods and rely on chemical fertilizer in order to maintain soil fertility (6, 53). Under intensive and continuous cropping where large doses of narrow spectrum fertilizers are applied, nutrient imbalances, especially those of sulphur and the micronutrients, may arise and increase in frequency and severity with increases in production intensity (59). In an effort to better understand these imbalances, the authors felt a need to consolidate relevant information in the form of a literature review.

2.1. Fertilizer elements

2.1.1 Phosphorus.

The importance of phosphorus in WASAT agriculture is widely recognized and thus has been more thoroughly studied than any other mineral element. Literature reviews have been compiled by Olsen and Engelstad (70), Bouyer (18) and Pichot and Roche (75).

Total phosphorus in surface layers of WASAT soils ranges from about 80 - 150 ppm (17, 36, 41, 67), the exceptions being soils derived from Basalt and Vertisols. Bouyer (18) and Berger (9) found that in general soils containing less than 220 - 390 ppm P responded to phosphate applications indicating the likelihood of widespread P deficiency in WASAT regions.

Losses of soil phosphate due to leaching are very small. Estimates from Senegal show annual losses in the range of 0.04 - 0.22 kg/ha (30). The main loss of P in WASAT regions occurs in crop removal and in soil erosion (53).

Under high levels of production total uptake of P by crops may range from 20 - 40 kg/ha, most of which is removed as grain and not returned to the soil (59).

Phosphate availability and uptake are determined by its concentration at the root surface. Fried and Broeshart (38) and Larsen (60) describe phosphate availability as being controlled by intensity and quantity factors.

The concentration of phosphate in the soil solution (intensity factor) is very low in most WASAT soils. Saturation extracts from Nigerian Ferruginous soils were found to range from 0.01 - 0.02 mg P/1 (7).

The quantity factor is dependant on the maintenance of labile phosphate or the pool of readily desorbed phosphate (59). Isotopic exchanges is usually the method employed when estimating labile phosphate. Isotopically exchangeable P in Nigerian Ferruginous soils contained between 7 and 11 ppm (7). These amounts however are low when compared to unfertilized soils in England where values ranged from 50 - 150 ppm P. (61).

2.1.2 Nitrogen

Nitrogen is one of the most limiting factors associated with crop production in WASAT regions. Unfortunately, the nitrogen balance and other components (gains, losses and availability) are not fully understood (43).

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Total soil N in WASAT soils ranges from 0.008 - 2.90 per cent with an average value of 0.051 per cent in the surface layers (0-15 cm) of cropped soils (51). Total N content is influenced by annual rainfall and soil clay content (51).

Gains of nitrogen via precipitation or bacterial fixation are small. Jones and Bromfield (52) reported the annual content of N in rainfall at Samaru to be 4 - 5 kg N/ha.

Crop legumes in WASAT regions are thought to fix small if not negligible amounts of nitrogen (53). Estimates from northern Nigeria indicate that a 3 tonne/ha dry matter crop of groundnuts fixes about 150 kg/ha of nitrogen (23). This amount however is substantially reduced when the haulms are removed for fodder as is the traditional practice in WASAT agriculture (90).

The loss of nitrogen occurs as a result of several activities, the most important being the burning of crop or fallow residues and leaching. Burning of crop or fallow residues accounts for annual losses of 20 - 40 N/ha (68, 88).

Nitrogen loss due to leaching depends on the rate of mineralization and nitrification, amount and type of fertilizer (11), soil type (53), vegetative cover (85) and the amount of rainfall percolating through the soil (30). In one meter of soil depth leaching losses of N were estimated to be between 5 and 30 kg/ha per annum (30).

The availability of nitrogen to crops is dependant on the rate of mineralization and the balance of gains and losses of soil N (53, 59). The most important factor governing N mineralization in WASAT soils is the Birch effect. Birch (10) found that repeated cycles of soil wetting and drying led to repeated flushes of N mineralization at each rewetting. This phenomena was demonstrated in Senegal where repeated wetting and drying released 58 kg N/ha at Bambey and 157 kg N/ha at Sefa (13,14).

2.1.3 Potassium

Potassium deficiency in WASAT agriculture has been identified in Nigeria but only under intensive and lengthy cropping (4, 48, 50). Charreau and Poulain (31) and Bockelee-Morvan (15) however, reported crop response to K fertilizer on a number of crops in Senegal.

Total soil K contents are often high and vary greatly with parent material (1, 35, 69, 89). Surface soils (0 - 15 cm) of northern Nigeria over basement complex rocks contained a mean of 2.2 per cent K while samples over sandstone contained only 0.08 per cent K (89).

Exchangeable K tends to be low depending on clay content and intensity of mineral decomposition (59). In 41 soils from Burkina Faso, Dupont de Dinechin (35) recorded a mean value of 0.25 me/100 g. Further studies in northern Nigeria on soils dominant in Kaolinite yielded K values of 0.18 - 0.25 me/100 g and a mean ratio of total to exchangeable K of about 100 (89).

2.2. Macroelements

2.2.1 Calcium and Magnesium

The dominant exchangeable cations in virtually all WASAT soils are calcium and magnesium (53). Consequently, few deficiencies have been reported.

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Amounts of exchangeable Ca and Mg tend to be low, usually ranging from 0.3 - 3.0 me/100 g for Ca and 0.2 - 2.0 me/100 g for Mg. (59).

Calcium deficiency is known to cause low shelling percentages in groundnuts on some sandy soils in Nigeria (5, 64). Meridith (64) found that calcium deficiency caused "blind nuts" when soil exchangeable calcium was 0.04 -0.08 me/100 g whereas when full nuts were produced soil exchangeable calcium was 0.15 - 0.24 me/100 g.

2.2.2 Sulphur

The sulphur status of WASAT soils remains delicate due to considerable losses through burning and leaching and negligible additions from rainfall, dust and the atmosphere (25, 26, 27, 30).

Although subsoil reserves of S can be quite large (22), S deficiency occurs widely in WASAT regions and has been observed in crops of cotton (19, 20, 39), groundnuts (41, 44, 45, 66) and cereals (77). Sulphur deficiency would be more prevalent but for the fact that many commercial fertilizers contain sulphur and mask its deficiency (59).

Sulphur is found in organic combinations and because of the inherently low O.M. content of WASAT soils, sulphur content tends to be low. Goldsworthy and Heathcote (41) found that northern Nigerian soils contained a range of 18 - 132 ppm (mean : 45 ppm).

It appears that sulphur deficiency is not confined to any one soil type (86), but that availability depends on the depth and rooting pattern of the crop (22) and climatic conditions such as repeated wetting and drying of soils (24).

The sulphur balance in WASAT soils has become increasingly important due to shortened fallow periods and more intensive cultivation (68). Sulphur deposits from rain water range from 0.5 - 1.9 kg S/ha per annum (mean: 0.226 kg/ha) while sulphur deposited directly from the air was 0.8 kg/ S/ha (26, 27).

Losses of sulphur due to leaching and burning of crop or fallow residues can be quite large. Leaching losses range from 5-30 kg S/ha per annum and vary according to soil type, crop, rainfall and fertilizer additions (29, 85). Still, the major contributing factor in the widespread sulphur deficiency of WASAT soils is the burning of crop or fallow residues (53, 59). Charreau (30) found that burning of crop or fallow residues resulted in annual losses of 5 - 10 kg S/ha.

2.3. Micronutrients

2.3.1 Boron

The most economically important of all micronutrients in WASAT regions is boron, affecting the production of cotton (21, 80, 81), groundnuts (88) and forest trees (Eucalyptus spp.) (38).

Total boron content in WASAT soils is generally low (32, 79). Nalovic and Pinta (66) reported low levels of total B (3.3-18.2 ppm) for surface soils in northern Cameroon. Very low levels of total B were reported in Mali where data from surface horizons yielded a range of 0.18-0.31 ppm (74).

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Total boron and boron availability (hot-water-soluble) are most dramatically affected by toposequence position (32) and parent material (8). Upper slope profiles contain more total B than those lower on the profile and profiles over basement complex rocks contain more total B than those over sandstones. Factors affecting B availability include soil pH levels above 6.3 (73) and coarse textured soils, low in organic matter which dry out quickly (80).

Boron deficiency has been found to cover a wide area of the cotton growing belt in northern Nigeria where most localities were well below the critical minimum of 0.1 - 0.2 ppm hot-water-soluble B (81). Deficiency however may vary within a small area due to moisture stress, crop variety and fertilizer application (21, 58).

2.3.2 Molybdenum

Molybdenum deficiencies occur throughout the groundnut growing areas of north-west Senegal (63), northern Ghana (81) and in northern Nigeria (47, 49). These deficiencies can be expected to occur on acid soils (83) which are high in active iron oxides (59).

Total molybdenum in WASAT soils is low (34, 78). Data from selected profiles in Nigeria showed a range of 3 - 42 ppm total Mo (32).

Soil applications of Mo has led to improved growth, nodulation, N fixation and seed yield in groundnuts (40, 63). Pod yield response however has been erratic because of the increase in leaf area and therefore drought susceptability (40). Heathcote and Fowler (49) showed that the use of ammonium molybdate applied to groundnut seeds greatly increased haulm and pod yield. Similar results were obtained with maize where the use of germplasm inherently low in Mo aggravated deficiency (82).

2.3.3 Zinc

Zinc deficiency in WASAT agriculture has largely been associated with maize grown on sandy soils in Nigeria (3) and rice grown on Vertisols (57).

Total zinc content of WASAT soils varies greatly according to vegetation, profile depth (58) and toposequence position (32). Osiname and Kang (unpublished data) observed a range of 12 - 45 ppm Zn for the forest region and 9 - 35 ppm Zn for the savanna region of Nigeria. Top soil samples from Mali showed a range of total Zn between 1.9 - 4.8 ppm (74). As with most micronutrients, upper slope profiles contain more total Zn than those lower on the toposequence (32).

Maize yield increases of up to thirty three per cent have been obtained with the application of low zinc rates (3, 72). These zinc responses however correspond to soils with extractable zinc levels of less than 1 ppm (58).

2.3.4 Manganese

Few reports on manganese deficiency in WASAT agriculture exist, however lime-induced Mn deficiency has been observed in pot experiments with maize (54) and cowpeas (55) grown on sandy acid soils.

More important in WASAT agriculture is the problem of Mn toxicity (58). Toxicity most often arises with the use of acidifying fertilizers and has been observed on such crops as maize, cowpeas and cotton (6, 42, 62).

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Total Mn is considered to be adequate in most WASAT soils (78). Nigerian surface soils ranged from 0.02 - 0.19 per cent total Mn (32). Similar results were obtained in Cameroon and Benin where total Mn in surface soils ranged from 0.044-0.24 per cent (65) and 0.013 - 0.20 per cent (76), respectively.

Total Mn is affected by toposequence position (32) and parent material (28, 3[illegible], 84). Upper slope profiles were shown to contain more total Mn than those lower on the toposequence and profiles over basement complex rocks contained more total Mn than those over sandstones.

2.3.5. Copper

Despite low extractable levels of copper in WASAT soils, fertilizer response has yet to be observed in field experiments (71). No reports of deficiency or toxicity have been recorded.

Total copper in surface soils of Nigeria ranged from 7 - 59 ppm (32). Nalovic and Pinta (65) reported a range of 7.3 - 54.0 ppm total copper.

2.3.6. Iron

There have been no reports of iron deficiency or toxicity under normal cropping conditions in WASAT regions. There are however, indications that iron deficiency may result with pH increases following the burning of crop residues (33, 46, 56).

Total iron content of WASAT soils is moderate to high. Surface soils in Nigeria were found to contain 0.63 - 7.63 per cent total iron (32) while data from surface soils in Ghana contained only 0.13 - 0.45 per cent (2). Total iron increases with profile depth and upper slope profiles contained more total iron than those lower on the toposequence (32).

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