Soil test based Phosphorous Calibration for Soybean [*Glycine max* (L.) *Merrill*] Production on Nitisols in Assosa Zone of Benishangul Gumuz Region, Western Ethiopia

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ARTICLE INFO	ABSTRACT

Soil test based phosphorous (P) calibration study was conducted on Soybean on Nitisols of farmers' fields in Assosa Zone. The experiment was arranged in a randomized complete block design with six levels of phosphorous fertilizer (0, 5, 10, 15, 20 and 25 kg ha^{-1}) with three replications. The results revealed substantial responses of Soybean to phosphorus fertilizer rates on plant height, pod numbers per plant and seed yield. Seed yield increased significantly from 1761 to 2300 kg ha^{-1} with increase in the level of P fertilizer from the control to 46 kg P ha^{-1}. The magnitude of increase in seed yield due to application of 46 kg P ha^{-1} was 30.6 % higher as compared to the control. Extractable soil P concentrations (Bray II, 0- 20 cm depth) three weeks after planting significantly responded to P fertilizer rate. Correlations of relative yield with soil test phosphorous values showed that the critical soil P concentration and average phosphorous requirement factor (Pf) calculated from soil test phosphorous values of all treatments for the study area were 8.5 and 6.55 mg kg^{-1}, respectively.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is one of the most widely grown leguminous crops in the world (Guo et al. 2011). This crop is widely cultivated on world arable soils with low phosphorus (P). Investigation of soybean yield and related yield component traits with different P rates will help improve field management to optimize soybean production and seed quality. Low P in soil is a major constraint for soybean growth and production, which are atmospheric nitrogen (N_2) dependent (Bordeleau and Prévost, 1994) because P is particularly important for symbiotic N_2 fixation in legumes (Zahran 1999). Phosphorous is the most yield limiting of soil-supplied elements, and soil P tends to decline when soils are used for agriculture (David and David, 2012). Studies on Nitisol areas, in the western Ethiopia are marginally to severely deficient in P. The blanket recommendations that are presently in use all over the country were issued several years ago, which may not be suitable for the current production systems (Taye et al*.,* 2002; Gete et al., 2010). Since the spatial and temporal fertility variations in soils were not considered, farmers have been applying the same P fertilizer rate to their fields regardless of soil fertility differences.

Phosphorus calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current P recommendations (Getachew and Berhane, 2013, Getachew et al., 2015). They enable to revise fertilizer recommendations for an area based on soil and crop type, pH and soil moisture content at time of planting. An accurate soil test interpretation requires knowledge of the relationship between the amount of a nutrient extracted by a given soil test and the amount of plant nutrients that should be added to achieve optimum yield for a particular crop (Muir and Hedge, 2002; Watson and Mullen, 2007). Soil tests are designed to help farmers predict the available nutrient status of their soils. Once the existing nutrient levels are established, producers can use the data to best manage what nutrients are applied, decide the application rate and make decisions concerning the profitability of their operations (Girma, 2016). However, local assessments for the soil P critical levels and soil P requirement factors even for the major crops of the country are negligible (Getachew et al., 2015). Currently, soil fertility research improvement is agreed with respect to site specific fertilizer recommendation in the country.

Soil test-based and site-specific nutrient management has been a major tool for increasing productivity of agricultural soils. The aim of the soil test calibration is to obtain correlation between the contents of the available nutrients in the soil and the crop responses to applications of nutrients in selected areas. Therefore, the objectives of this study were to correlate the Bray-II soil test P with the relative seed yield response of Soybean across selected Nitisol areas of Assosa Zone, to established preliminary agronomic interpretations, and to determine the critical P concentration and P requirement factor.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted in Assosa Zone, in two districts, namely Bambasi and Assosa, western Ethiopia, in the main rainy seasons of 2012, 2013 and 2014. The study sites are located between 1300 and1470 m.a.s.l. with the minimum and maximum temperatures of 14.5 and 28.8^{o}C, respectively. It is characterized by hot humid agro-ecology having mean annual rainfall of 1358 mm per annum. The predominant soil type is Nitisols (AsARC, 2014).

Treatments and Experimental Design

The treatments comprised six levels of phosphorous fertilizer (0, 5, 10, 15, 20 and 25 kg P ha^{-1}). The experiment was laid out in a randomized complete block design with three replications. The gross plot size was 4.5 x 5.1m = 22.95 m^2.The net plot size was determined with area and plant density leaving the one outermost row and sides of each row. The harvested plot area was 15.3 m^2. The source of P was triple super-phosphate (TSP). The experimental land was well prepared. Each plot and block was separated by 0.75m and 1.5m, respectively. Soybean (*Belessa 95*) was used for the experiment with row planting method. Important agronomic practices were uniformly applied to all experimental plots as often as required.

Soil Sampling and Analysis

Composite soil samples were collected from the experimental plots in a diagonal pattern from the depth of 0-20 cm before planting. Uniform slices and volumes of soil were obtained in each sub-sample by the vertical insertion of an auger and made a composite soil sample. The soil samples were dried, ground using a pestle and a mortar and allowed to pass through a 2-mm sieve and analyzed for the selected chemical properties mainly organic carbon, total nitrogen, soil pH and available phosphorus using standard laboratory procedures. Organic carbon(OC) content was determined by the volumetric method (Walkley and Black, 1934) as described in the Food and Agriculture Organization (FAO) guide to laboratory establishment for plant nutrient analysis (FAO, 2008) using 1.0 g of the prepared soil sample. Total nitrogen was analyzed by Micro-Kjeldhal digestion method with sulphuric acid (Jackson, 1962). The pH of the soil was determined according to FAO (2008) using 1:2.5 (weight/volume)

soil sample to water solution ratio using a glass electrode attached to digital pH meter. Available phosphorus was determined by the Bray II method.

Experimental Procedures

Land preparation was done with local maresha using oxen plough. An improved soybean cultivar (*Belessa 95*) was planted to the specified treatments. Sowing was made from end of June to the first week of July depending on the onset of rainfall. Weeding and harvesting were done at the appropriate time according to the research recommendations. Application of phosphorus fertilizer was done by banding the granules of TSP at a depth of 10 cm below and around the seed at planting. Harvesting was done at physiological maturity when the leaves of the soybean plants senesced. Agronomic parameters collected were plant height (average of ten randomly reselected plants per plot), number of pods per plant, seeds per pod (average of ten plants) and seed yields and thousand seed weight. The harvested materials were sun-dried and manually threshed. After threshing, seeds were cleaned, weighed and adjusted at 10% moisture level. The seed yields recorded on plot basis were converted to kg ha^{-1} for statistical analysis.

Determination of critical P concentration (Pc): to correlate relative yield vs. soil test P values and determine critical P concentration, the available P was extracted from the soil samples taken three weeks after planting from each plot of all experimental fields using Bray-II method.

The Cate-Nelson graphical method (Dahnke and Olsen, 1990) was used to determine the critical P value using relative yields and soil test P values obtained from 20 P fertilizer trials conducted at different sites. To assess the relationship between seed yield response to nutrient rates and soil test P values, relative seed yields in percent were calculated as follows:

$$: \quad \frac{Relative\ yield(\%)}{\frac{yield}{maximum\ yield}} x100 \qquad (1)$$

The scatter diagram of relative yield (y-axis) versus soil test values (X-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P fertilizer requirement while the observations in the lower right quadrant underestimate the fertilizer requirement. The intersecting lines were moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). The point where the vertical line crosses the X-axis was defined as optimum critical soil test level (Dahnke and Olsen, 1990).

Determination of P requirement factor (P$_f$): phosphorus requirement factor (P$_f$) is the amount of P in kg needed to raise the soil P by 1mg kg^{-1}. It enables to determine the quantity of P required per hectare to raise the soil test by 1mg kg^{-1}, and to determine the amount of P fertilizer required per hectare to bring the level of available P above the critical level (Nelson and Anderson, 1977). It was calculated using available P values in samples collected from unfertilized and fertilized plots. Phosphorous requirement factor was expressed as:

$$Pf = \frac{kg\ P\ applied}{\Delta\ Soil\ P} \qquad (2)$$

Therefore, the rate of P fertilizer to be applied (*Pa*) was expressed in terms of critical P concentration (*P$_c$*), initial soil P value (*P$_i$*) and P requirement factor(*P$_f$*).

$$Pa = (Pc - Pi)\ x\ Pf \qquad (3)$$

Statistical analysis

The data were subjected to analysis of variance using the procedure of SAS statistical package, version 9.0 (SAS Institute, 2001). Whenever treatment effects were significant, the means were separated using the least significant difference (LSD) test at 5 % level of significance.

RESULT AND DISCUSSION

Soil Chemical Properties before Sowing

Soil chemical properties were analyzed for the surface composite soil sample taken from the experimental field. According to the rating of Landon (1991), the soil used for this study ranged from very strongly acidic (pH 4.71) to very alkaline (pH 8.8) classes. The exchangeable K of the soil before the application of the treatments ranged from 0.02 to 3.64 Cmol$_{(+)}$kg soil^{-1}. All experimental soils had deficient to adequate K content. According to Landon (1991), available (Bray II extractable) soil P level of less than 10 mg kg^{-1} is rated as low, 11-31 mg kg^{-1} as medium and greater than 18 mg kg^{-1} is rated as high. Thus, most trial location had very low to medium available (Bray II extractable) P (Table 1). Following the rating of total N by Landon (1991), > 1% is rated as very high, 0.5 to 1% high, 0.2 to 0.5% medium, 0.1 to 0.2% low and < 0.1% as very low N status. The experimental soils qualify for very low to medium total N. Similarly, the organic carbon (OC) content of the soil was also very low to low in accordance with Landon (1991), who categorized OC content as very low (< 2%), low (2- 4%), medium (4-10%), high (10-20%). The very low OC and low N content in the study area indicate low fertility

status of the soil. This could be due to continuous cultivation and lack of incorporation of organic materials (Table1).

Table1: Soil nutrient contents of the trial sites before planting Soybean in 2012-2014

Sites	pH(1:2.5H$_2$O)	OC (%)	TN (%)	P(mg/kg)	K(Cmol$_{(+)}$kg soil^{-1})
1	4.91	2.34	0.13	3.20	0.22
2	4.71	2.53	0.16	12.40	3.64
3	5.42	2.77	0.17	3.72	0.91
4	5.25	2.22	0.16	2.20	0.40
5	4.78	1.68	0.15	3.40	0.19
6	5.05	2.81	0.16	5.00	0.61
7	5.28	2.88	0.19	2.60	0.36
8	5.22	2.49	0.17	3.40	0.42
9	6.49	2.40	0.17	3.14	0.43
10	6.00	2.64	0.21	4.29	0.71
11	6.30	2.16	0.17	2.15	0.12
12	6.17	2.16	0.19	1.65	0.21
13	7.99	2.64	0.22	0.17	0.24
14	6.33	2.56	0.22	0.86	0.43
15	5.31	2.32	0.18	0.58	0.70
16	5.36	2.80	0.22	5.80	0.67
17	5.18	2.64	0.21	2.59	0.05
18	5.19	2.12	0.18	3.60	0.02
19	8.80	2.68	0.24	3.14	0.55
20	6.17	2.16	0.19	1.65	0.21

Yield and Yield Components

Plant height, pod numbers per plant and seed yield of soybean significantly influenced by application of phosphorus fertilizer while there is no significant difference observed on height of first fruiting branch and seeds per pod (Table 2).

Application of P fertilizer had significantly increased the number of pod per plant (Table 2).Significantly higher number of pods per plant (29.1) was recorded with P rates of 25 kg ha^{-1} over the control treatment. However, there is no significant difference between applied P fertilizer rates. The lowest pods per plant (23.5) were recorded at control (no application of P fertilizer). The result is agreed to Shubhashree (2007) and Singh & Singh (2000), who reported that applications of different rates of phosphorus fertilizer influence number of pods per plant Similar results also reported by Meseret and Amid (2014), who indicated that application of phosphorus fertilizer had significantly increased number of pods per plant in common bean. Thus the increment of number of pods per plant due to application of P fertilizer confirms with P fertilizer promotes the formation of nodes and pods in legumes (Buttery, 1969). This might be the liberal availability of plant nutrients which stimulated the plants to produce more pods per plant as compared to other treatments as phosphorus powerfully encourages flowering and fruiting.The analysis of variance for plant height (Table 2) showed significant response to P rates levels. The highest plant height (67.9cm) was obtained at applied P rate of 20 kg ha^{-1}, whereas the lowest plant height (55.7cm) was recorded in the control treatment. However; Plant height did not significantly differ between applied P fertilizer rates. The increment of plant height with increasing P fertilizer application up to optimum level might be the nutrient are involved in vital plant functions and contribute to enhanced growth in the height of the plant. Similarly, Rashid and Khan (2008) reported that plant height was linearly increased with increasing level of fertilizer. This result also resembles the findings of Jain and Trivedi (2005) who reported an increase in plant height with P$_2$O$_5$ application.

Table 2: Effects of P on yield and major yield determinant parameters of soybean at Assosa Zone (2012-2014)

P (kg/ha)	Height of first fruiting branch	Pods per plant	seed per pod	Plant Height (cm)
0	8.4	23.5	2.28	55.7
5	8.7	26.2	2.26	62.1
10	9.1	26.2	2.25	64.6
15	8.3	27.6	2.23	66.5
20	9.5	28.6	2.23	67.9
25	9.2	29.1	2.25	67.0
Mean	8.9	26.8	2.25	64.0
CV	25.5	34.9	13.86	18.5
LSD	NS	3.6	NS	4.6

The applied rates of P fertilizer have significantly increased the Seed yield of soya bean. The maximum (2300 kg ha^{-1}) seed yield was recorded at application of 20 kg P ha^{-1}; whereas the minimum (1761 kg ha^{-1}) was recorded on control. But, there was no a significant difference among applied P fertilizer rates (Figure 1). Seed yield increased significantly from 1761 to 2300 kg ha^{-1} with increase in the level of P fertilizer from the control to 46 kg P ha^{-1}. The magnitude of increase in grain yield due to application of 46 kg P ha^{-1} was 30.6 % higher as compared to the control. Increased in seed yield with the increase in rate of 46 kg P$_2$O$_5$ might be due the importance of phosphorus in a number of metabolic functions and is especially important for grain formation (Balyan and Singh, 2005). This increment in dry matter yield with application of P fertilizer might be due to the adequate supply of P could be attributed to an increase in number of branches per plant, and leaf area.

This in turn increased photosynthetic area and number of pods per plant, which demonstrates a strong correlation with dry matter accumulation and yield. This is in agreement with the study conducted on soybean indicated that increasing the phosphorus concentration in the soil increased the whole plant dry matter accumulation and total leaf area (Jennifer, 2000). Seed yield showed decline after 20 kg P ha^{-1} application which may be due to toxic or antagonistic effect of higher doses of phosphorus application (Ripudaman *et al.*, 2014). The maximum yield attainable at any given location depends not only on the soil available nutrients and the amounts of fertilizer applied, but also on the amount and distribution of rainfall during the crop season. Availability of nutrients to crops is a function of the soil, crop, environment, and management; their interactions affects fertilizer use efficiency and the crop growth condition (Smilde, 1987; Fageria, 2009).
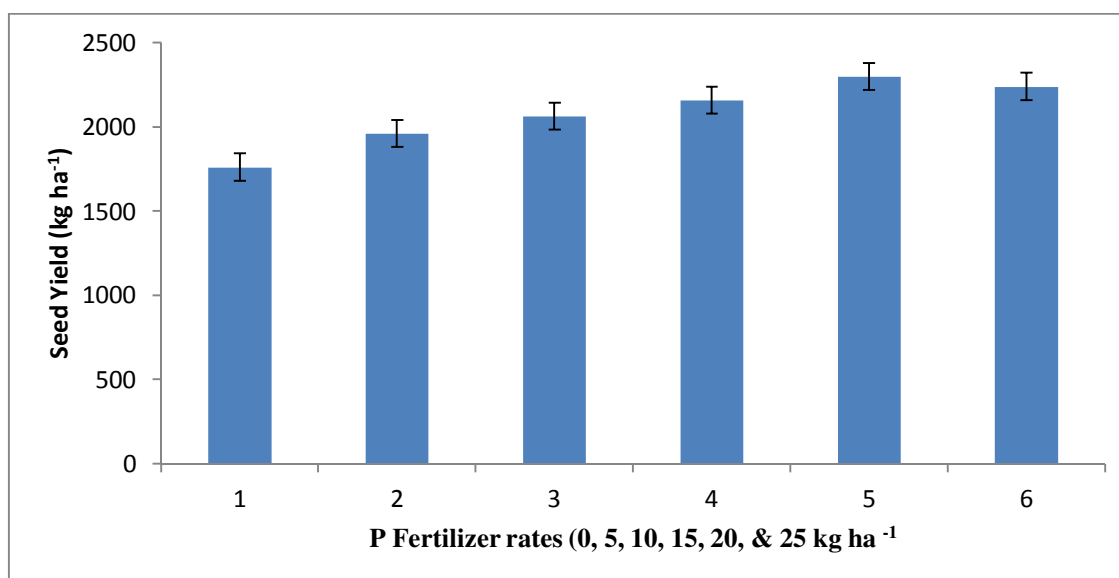
Figure 1: Effect of P fertilizer rates on seed yield of Soybean

Critical P concentration (Pc) and P requirement factor (Pf)

Soil P values determined three weeks after planting differed significantly ($P \leq 0.05$) among P levels. The effect of P fertilizer treatments resulted in mean soil test P values 1.85 to 56.46 mg kg^{-1}.The increase in soil P content in response to P fertilizer application was linear up to 20 kg P ha^{-1}. The highest mean soil P concentration (56.46 mg kg^{-1}) was recorded from 25 kg P ha^{-1} (Table 3). The relationship between relative Seed yield response and soil P measured with the Bray-II method is shown in the Figure 1. The critical P concentration (*Pc*) was determined from the scatter diagram drawn using relative seed yields of soybean and the corresponding soil test P values for all P levels (0-25 kg ha^{-1}). According to the Cate-Nelson method, the critical levels of Bray-II P in the top 20 c0m of soil is about 8.5 mg kg^{-1}; at values of greater than or equal to

8.5 mg kg^{-1}, the crop achieved about 80% of its maximal yield in the absence of P fertilizer application (Figure 1). This implies that P fertilizer application could be recommended for a build-up of the soil P to this critical value, or maintaining the soil P at this level. Increasing P beyond this level, the cost of additional P fertilizer to produce extra yield would likely be greater than the value of additional yield. Thus, in soils with available P status below 8.5 mg kg^{-1}, yield of Soybean could show a significant response to applications of P fertilizers. Whereas in areas with available P status greater than 8.5 mg kg^{-1}, the P concentration in the soil exceeds crop needs so that further addition of P fertilizer may not result in a profitable yield increase. A critical concentration of 13 mg P kg^{-1} for corn response within this category (13-20 mg P kg^{-1}) may be considered small, and maintenance fertilization can be recommended based on expected nutrient removal with harvest (Mallarino , 2003).
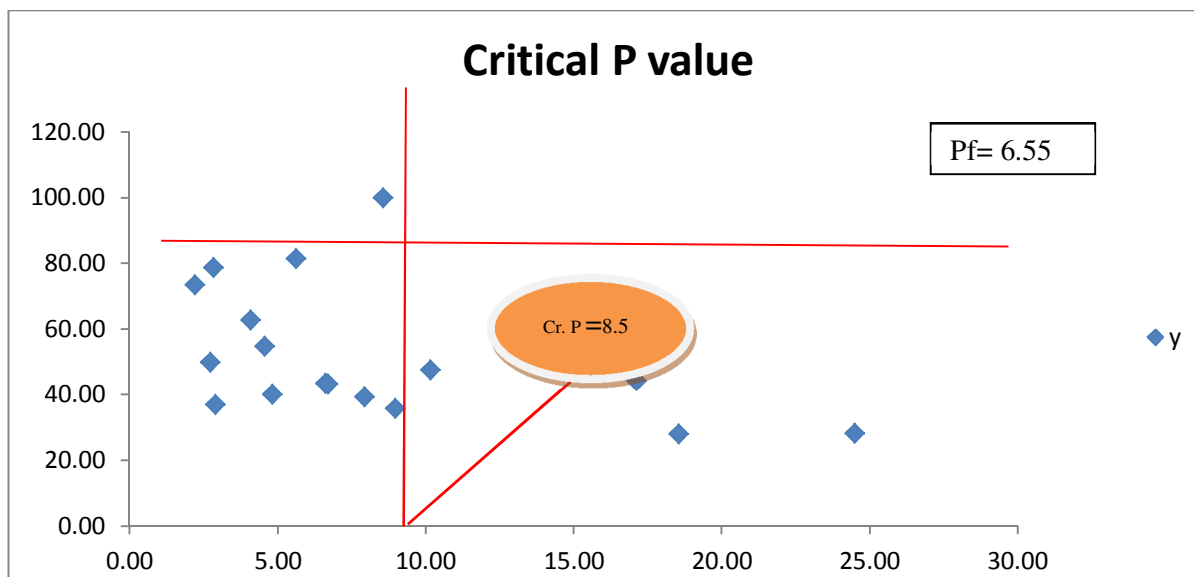

Figure 2: Relationships between relative yield response of Soybean and soil-test P measured using Bray-II method. The arrow indicates the critical P concentration (*Pc*) for Soybean on Nitisols

When the soil test value is below the critical level, additional information is needed on the quantity of P required to elevate the soil P to the required level. This is the P requirement factor (*Pf*), the amount of P required to raise the soil test P by 1mg kg^{-1}, computed from the difference between available soil test P values from plots that received 0–25 kg P ha^{-1} using the second formula mentioned above. Accordingly, the calculated *Pf* were 4.7–7.73 and the overall average *Pf* of all treatments for the study area was 6.55 (Table 4). Thus, the rate of P fertilizer required per ha can be calculated using the soil critical P concentration, initial soil P determined for each site before planting (Table 1) and the P requirement factor as indicated above in the third formula.

Phosphorous fertilizer application at optimum level is necessary to improve seed yield of soybean. Soil fertility is sub-optimal for the production of soybean in western Ethiopian particularly on Nitisols where soil pH and the associated P availability are low. Following the pre-planting soil analysis results, all of the trial sites had lower soil P values than the critical P concentration. This had a direct relationship with the crop growth and seed yields. In most cases, soil pH less than 5.5 is deficient in available P and exchangeable cations (Brady and Weil, 2010). In such soils, the proportion of P fertilizer that could be available to a crop becomes inadequate (Brady and Weil, 2010), unless amended through organic matter or liming. The results seem promising and could

be used as a basis for soil-test P fertilizer recommendation for the production of Soybean on Nitisol areas Benishangul Gumuz Region of Western Ethiopian,. Nevertheless, to develop an effective guideline for wider applicability of soil test based fertilizer recommendations, more research assisted by appropriate soil P extraction methods is required to generate sufficient information for the most important crop-soil systems.

Table 3: Determination of P requirement factor for linseed on Nitisols (2012-2014)

P rate (kg ha⁻¹)	Soil test P (mg kg⁻¹)		P rise over control	Phosphorus requirement factor (Pf)
	Range	Average		
0	1.85-10.54	5.38		
5	2.26-12.15	6.03	0.65	7.73
10	2.0-20.07	7.47	2.09	4.79
15	2.07-30.62	7.49	2.11	7.11
20	1.95-30.46	8.11	2.73	7.34
25	2.44-56.46	9.7	4.31	5.79
Average				**6.55**

CONCLUSIONS

Positive effects of P fertilizer on yield and some yield components of Soybean on Nitisols of Assosa zone of Benishangul Gumuz Region. The critical soil P concentration and average phosphorous requirement factor (Pf) calculated from soil test phosphorous values of all treatments for the study area were **8.5 and 6.55 mg kg⁻¹**, respectively. The results may be used as a basis for P fertilizer recommendations for the production of Soybean on Nitisol of the study area. They can also be used for future intensification in other areas for developing a system for soil-test P fertilizer recommendations. Further field trials involving different N levels, climatic conditions, soil P test methods, and perhaps limiting treatments, would further our understanding of limiting factors and facilitate better fertilizer recommendations.

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