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# Soil Test Crop Response Based Phosphorous Calibration Study for Maize in Sibu Sire District, Western Oromia, Ethiopia

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**Abstract:** Calibration of soil test P could be a stage in determining P fertilizer rates to meet plant P requirements and soil nutrient availability of phosphorous. The objective of this study was to determine the critical phosphorous (Pc) and phosphorous requirement factor (Pf) for maize production in the district. Field experiments, which were laid out in a randomized complete block design (RCBD) with three replications, were conducted from 2018 to 2021. Maize response to different levels of phosphorus was conducted at 17 sites in the Sibu Sire District, East Wollega Zone, Oromia Regional State, during the 2019/20 and 2021 cropping seasons. Partial budget analysis showed 138 kg/ha of N was economically optimal for the production of maize in the Sibu Sire district. The phosphorus calibration study included the application of 0, 10, 20, 30, 40, and 50 kg P $ha^{-1}$ with a recommended 138 N kg $ha^{-1}$ The critical concentration and requirement factor of phosphorus on maize in the study area were 10 mg $kg^{-1}$ and 20.63 kg/ha, respectively. Using the calibrated phosphorus would enhance the profitability of maize production across the Sibu Sire district. This phosphorus requirement factor and critical phosphorus level can help give recommendations based on soil test phosphorus levels for maize production in the Sibu Sire district. Thus, in soils with an available P status below 10 mg $kg^{-1}$, the yield of maize could show a significant response to applications of P fertilizers. Whereas in areas with soil available P status greater than 10 mg $kg^{-1}$, the P concentration in the soil sufficient crop growth so further addition of P fertilizer may not result in a profitable yield increase. In addition, integration of this finding with other uses of biofertilizer, compost, vermicompost, and organic fertilizers is a basic to moving forward with yield, maintenance, and sustainability of soil health. Future research should focus on verifying results on farmland before implementing the technology in real-district agriculture.

**Keywords:** Calibration, Critical Phosphorous, Phosphorous Requirement Factor, Maize

## 1. Introduction

Phosphorus is one of the second essential plant nutrients. Phosphorus is one of the seventeen essential nutrients required for plant growth [1]. Phosphorus is a non-renewable resource found naturally at high concentrations in some minerals as well as in manures, the latter being the most economically exploitable sources of P. Due to its many uses, P is in high demand globally and the fact that the many functions which it performs cannot be substituted by any other element; makes its purported declining availability so serious. As a result, there is substantial global interest in minimizing P losses from land application and the overuse of P fertilizers, i e., applications above crop requirements that do not increase crop productivity [2].

Fertilizer P recommendations depend on (i) the existing level of available soil P, (ii) the optimum level of soil P for the crop to grow, and (iii) the level of fertilizer that must be added to raise available soil P to the optimum level. The soil testing for P is used to determine the amount of P required for crop production. Soil test P is also used for determining environmental risks associated with elevated levels of soil P

[3].

The basic construct of soil fertility guidelines and recommendations should include nutrient studies concerning soil and plant tissue analyses. These guidelines and nutrient management recommendations should be established through soil test and plant tissue correlation and calibration procedures. Soil test correlation can be described as the process of determining whether there is a relationship between plant uptake of a nutrient and/or yield with the amount of that nutrient extracted by a particular soil test. Different methods may be used to examine such a relationship. One example of a simple graphical method is the Cate Nelson method [4]. This method plots percent relative yield against soil test values which can effectively provide a visual indication of the reliability of a specified soil test and its correlation to plant response or the uptake of a specific nutrient.

In addition, this method also allows for the identification of a soil test critical level by dividing soil test values into soils that are likely or unlikely to respond to an added fertilization. Once this analysis has been conducted and a good correlation exists between the soil test and plant response, calibration analysis should be performed. Soil test calibration is the process of relating the soil test measurement in terms of crop response and it should describe soil test results in easily understood terminology and simplify the process of making fertilizer recommendations by placing soils in response categories [3]. Thus, the method for determining critical concentrations of soil test phosphorus for maize provides insight into P nutrition and can serve as a guide to improved agricultural practice in acidic soils of West Oromia as an indicator of P deficiency in crop production [5]. Soil tests could help farmers to know the nutrient status of the soils which could serve as a prior to estimating site-specific fertilizer investments by the already resource-constrained farmers.

As inherent soil fertility varies for different soils, site-specific fertilization recommendation has long been proposed as more efficient than blanket soil nutrient management. Across Ethiopia, and particularly in the study are blanket recommended rates of N and P are used in maize cultivation. Overall, to develop a valid soil test phosphorous recommendations for wider applicability using low, medium, and high categories, several years of research is required to generate sufficient information for the most important crop-soil system [6]. In Ethiopia, 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 [7]. 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. Availability of nutrients to crops is a function of the soil, crop, environment, and management; their interactions affect fertilizer use efficiency and the crop growth condition [6]. These factors need to be considered when using methods to calibrate soil-test nutrient values with relative grain yields. The soil test-based calibration study provides information on how many nutrients should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current P recommendations [8].

Application of fertilizer concerning initial soil fertility status and crop requirement leads to economic and judicious use of fertilizers. Experiments conducted by different researchers to decide the rate of fertilizer under different research stations and their surrounding on-farm resulted in different rates of recommendations in terms of both P and N [9]. Trials carried out in many localities across Ethiopia for about nine years also recommend different rates of P and N in accordance with crop and soil types [10]. However, the current maize grain yield has declined regardless of using improved maize varieties and NP fertilizers even in high maize growing potential areas of western Oromia.

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 [6, 11]. However, local assessments for the soil P critical levels and soil P requirement factors even for the major crops of the country are negligible. Currently, soil fertility research improvement is agreed for site-specific fertilizer recommendation in the country. The experiment was aimed at determining the economic rate of Nitrogen and Phosphorus fertilizers, assessing and evaluating soil test-based crop response phosphorus fertilizer requirement for maize in Sibu Sire District, and giving quantitative guidelines and recommendations of phosphorus fertilizer for maize in the district. The objectives of this study were to determine critical phosphorus concentration and phosphorus requirement factors and to established soil test-based fertilizer recommendations for maize production in the Sibu Sire district.

## 2. Materials and Methods

### *2.1. Description of the Study Area*

The study area is Sibu Sire district, is located about 270 km west of the capital city of Ethiopia, Addis Ababa. It lies between 8°56'- 9°23'N latitudes and 36°35'- 36°56' E longitudes and the study area (Figure 1). The altitude of the district varies from 1336 to 2500 meters above sea level. It has an estimated area of 1,132.51 km. About 74.2% of its surface area belongs to mid altitude agro climate, 7.53% of the land is highland agro climate, and the remaining 18.27% is classified as low land agro climate. The mean annual temperature and mean annual rainfall is 25°C and 1050 mm, respectively [12].

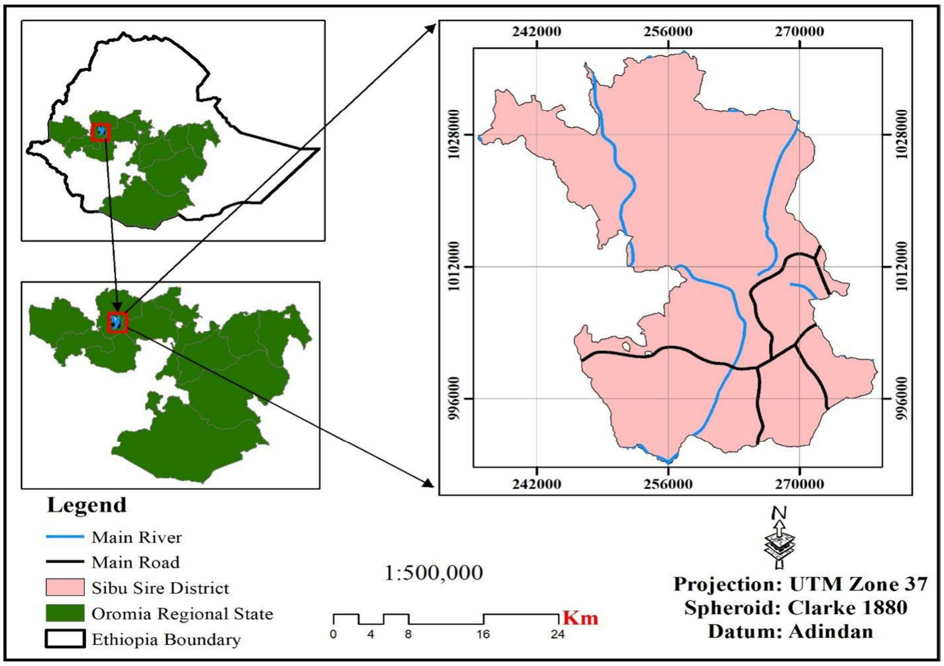


***Figure 1.*** *Location map of the study area.*

Agriculture provides the principal share of the source of revenue for the population of the district. Crop production took the lion's share followed by livestock production. The major crops include maize (25.6% of cultivated land), teff (20.5% of cultivated land), sorghum (16.5% of cultivated land), 'Niger seed (13% of cultivated land) followed by Finger millet (12.3% of cultivated land). The remaining percent of the cultivable land is covered by minor crops such as vegetables, roots and tubers, and some perennial crops [13].

### *2.2. Experiment Design*

The study was conducted in farmers' fields. The trials were laid out in RCBD using five levels of P (0, 10, 20, 30, 40 kg P/ha) and four levels of N (0, 46, 92, 138 kg N/ha) with three replications. Source of fertilizer, phosphorous is from DAP and Nitrogen from urea as treatments rates level design. The optimum amount of 138 kg N/ha was determined during the 1st year season of cropping. This amount of nitrogen nutrient applied for all plots uniformly for the 2nd and 3rd years. Lime was applied a month before planting based on the exchangeable acidity in the first year. Improved maize variety BH-661 was used. The spacing and plot size used 75*30cm and 5.m *6m values respectively.

Composite soil samples were taken before planting for 10 experimental trials field representative in first-year for determination of nitrogen nutrients. Soil samples were analyzed using a ratio of 2.5 ml water to 1 g soil [14] available P using Olsen method [15]. For the 2nd and 3rd years, 17 experimental trial field representatives were selected from the study area. A total of 17 soil samples were collected for analysis of soil pH, available P and Exchangeable acidity, and determination of lime requirement amount. Soil samples at a depth of 0-20 cm were collected from all experimental plots three weeks after planting for determination of PC and Pf of maize production in the study area.

Lime recommendation and application: Soil pH was analyzed at 1:2.5 (soil: liquid mixture) using a pH meter. The amount of lime recommended for a given field was estimated by using the following formula:

$$LR, CaCO_3\ (kg/ha) = \left[\frac{cmolEA/kg\ of\ soil * 0.20m * 10^4\ m^2 * B.D.\ (Kg/m^3) * 1000}{2000}\right] * CCE$$

B. D=Bulk density of soil, EA= Soil exchangeable Acidity) and CCE= Calcium Carbonate Equivalent.

Data Collection: Harvesting was done at physiological maturity. Grain yields were measured based on plant samples taken from ten central rows (2m x 2m= 4m$^2$) at the full maturity stage. Grain yield recorded on a plot basis was converted to kg ha$^{-1}$ for statistical analysis.

Economic Analysis: Economic analysis was performed to investigate the economic feasibility of the treatments (fertilizer rates). Partial budget analysis [16] was used to analyze economic benefits obtained from the different rates of fertilizers applied. The mean grain yield of the selected treatment was used in the partial budget analysis [16]. A partial budget, dominance, and marginal analysis were used. The average open market price (Birr kg$^{-1}$) for maize and the official prices of fertilizers were used for economic analysis. The dominance analysis procedure as detailed in [16] was used to select potentially profitable treatments from the range that was tested. The undominated treatments were ranked from the lowest (the farmers' practice) to the highest cost treatment. The % MRR between any pair of undominated treatments denotes the return per unit of investment in fertilizer expressed as a percentage. Grain yield was adjusted down by 10% to minimize the effect of trial managed on small plots that may vary from the yield level on farmer's fields. The optimum level of Nitrogen fertilizer rate was determined for maize production in the district. All cost estimates were taken based on the 2018/2019 cropping season.

$$\text{Marginal rate of return (MRR \%)} = \frac{marginal\ increasing\ in\ benefit}{marginal\ increasing\ in\ cost} * 100$$

Determination of the Critical phosphorus level: The Cate-Nelson diagram method was used to determine the critical phosphorus level, where soil phosphorus values put on the X-axis and the relative grain yield on the Y-axis. Soil available phosphorus determined through the Olsen method from the composite soil samples that had been taken from each plot three weeks after planting was used in correlation analysis with the relative grain yields of all data taken from seventeen sites and all treatments with their replication. The Cate-Nelson graphical method [3] was used to determine the critical P-value using relative yields and soil test P values obtained from 17 experimental sites of P fertilizer trials conducted at different P levels. The Y-X scatter diagram was divided into four quadrants and maximizing the number of points in the positive quadrants while minimizing the number of points in the negative quadrants. Pair of intersecting lines was drawn to divide into four sectors. The point where the vertical line crosses the X-axis was defined as the optimum critical soil test level [3].

Phosphorus requirement factor determination (pf); is the amount of P in kg needed to raise the soil phosphorus by 1 mg $kg^{-1}$. 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 fertilizer required per hectare to bring the level of available P above the critical level [17]. It was calculated using available P values in samples collected from unfertilized and fertilized plots. The phosphorous requirement factor was expressed as:

$$P\ requirement\ factor = \frac{kg\ of\ P\ applied}{Change\ of\ soil\ P}$$

Where; Kg of P= phosphorous nutrient applied, final soil phosphorous value – Initial soil value.

# 3. Result and Discussion

## *3.1. Soil Properties of the Study Area*

Soil test results of the study experiment sites before planting indicated that pH values of most soils were strongly acidic (Table 1). The soils pH in the studied area ranged from 4.51 to 5.98 and a mean value of 5.27 which are strongly acid. Accordingly, soil pH values are classified into five classes, strongly acidic < 5.5, moderately acidic 5.6 - 6.5, neutral 6.6 - 7.3, moderately alkaline 7.3 - 8.4, and strongly alkaline > 8.4 established by [18]. The most favorable pH for the availability of most plant nutrients corresponds roughly with the optimum range of 6 to 7 [19]. The range of soil reactions in experimental sites may limit crop production by influencing the availability of important plant nutrients. According to [20] a soil pH value below 5.5 could be an indication of the presence of an appreciable amount of exchangeable acidity and exchangeable $Al^{+3}$, and removal of exchangeable cations, such as calcium and magnesium. Olsen extractable method available phosphorous (P) of experimental soil in the district ranged from 1.3 to 15.41 ppm (Table 1). According to [20], available P soil level of less than 5 mg $kg^{-1}$ was rated as low, 5- 15 mg $kg^{-1}$ as a medium, and greater than 15 mg $kg^{-1}$ were rated as high. An available P soil a mean value was 7.30 ppm of the studied area rated at medium range. It needs additional P fertilizer to obtain the optimum yield in the study area.

***Table 1.*** *Selected experimental sites soil properties before planting in Sibu Sire District.*

| Experiment sites | Soil pH (1:2.5) $H_2O$ | Av. Phosphorous in ppm | Exch. Acidity (Cmol(+)/kg) |
|---|---|---|---|
| 1 | 5.98 | 14.84 | 0 |
| 2 | 4.54 | 6.84 | 1.94 |
| 3 | 5.48 | 3.42 | 0.32 |
| 4 | 5.74 | 5.9 | 0 |
| 5 | 4.93 | 3.63 | 1.36 |
| 6 | 5.08 | 1.3 | 1.11 |
| 7 | 5.5 | 3.01 | 0.47 |
| 8 | 5.07 | 4.94 | 0.39 |
| 9 | 5.76 | 9.73 | 0 |
| 10 | 5.46 | 5.05 | 0.3 |
| 11 | 5.63 | 13.45 | 0.17 |
| 12 | 4.51 | 15.41 | 1.67 |
| 13 | 5.31 | 7.78 | 0.26 |
| 14 | 4.82 | 5.74 | 0.73 |
| 15 | 5.05 | 6.15 | 0.47 |
| 16 | 4.94 | 4.68 | 0.26 |
| 17 | 5.82 | 12.28 | 0.14 |
| Mean value | 5.27 | 7.30 | 0.56 |

## *3.2. Critical Phosphorus Level and Phosphorus Requirement Factor*

Economic analysis using partial budget analysis showed that N fertilizer rate of 138 kg/ha was economically optimal for the production of maize in Sibu Sire. The N fertilizer rate of 138 kg/ha has a synergetic effect with phosphorus towards increasing grain yield. It was selected for critical P determination using the Cate – Nelson graphical method. Soil test phosphorous results were used to scatter the plot of relative grain yield versus phosphorous value. The Pc defined by the Cate- Nelson method in this study was 10 mg P $Kg^{-1}$, with a mean relative grain yield response of 80% (Figure 2). Hence, the scattered plots showed that 10 ppm was the critical phosphorus level for maize production in Sibu Sire District.

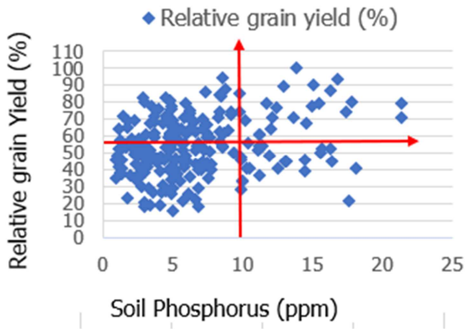


***Figure 2.*** *Scattered plot of relative grain yield (%) of maize and soil test phosphorus (Olsen) in Sibu Sire District.*

Phosphorus requirement factor was figured out from the differences between phosphorus values in the soil samples collected from plots that received phosphorus fertilizers. The phosphorous requirement factor values for the plots that received 10 kg P/ha, 20 kg P/ha, 30 kg P/ha, 40 kg P/ha and 50 kg P/ha were found to be 3.74, 9.35, 22.64, 20.14, and 47.32 values respectively recoded at the study area. The mean of these values, which represents the phosphorus requirement factor of the Sibu Sire district, was 20.63 P kg /ha or 47.24 $P_2O_5$ kg /ha (Table 2). Phosphorus requirement factor and critical phosphorous value can be used as a base for phosphorous fertilizer applied for maize production and productivity in the district.

***Table 2.*** *Phosphorous requirement factor determined in the Sibu Sire district.*

| P Fertilizer applied (kg/ha) | Soil Av. P (ppm) | P increase over the control (ppm) | P requirement factor |
|---|---|---|---|
| 0 | 12.10 | | |
| 10 | 14.78 | 2.68 | 3.74 |
| 20 | 14.24 | 2.14 | 9.35 |
| 30 | 13.43 | 1.32 | 22.64 |
| 40 | 14.09 | 1.99 | 20.14 |
| 50 | 13.16 | 1.06 | 47.32 |
| Mean | | 1.84 | 20.63 |

Therefore, the rate of P fertilizer to be applied was expressed in terms of critical P concentration (Pc), initial soil P-value (Pi) and P requirement factor (Pf).

$$\text{Phosphorours fertilizer rate in Kg of} \frac{P}{ha} = (Pc - Pf) * Pf$$

### *3.3. Economic Analysis*

The nitrogen fertilizer rate was determined based on economic analysis; the partial budget showed that fertilizer rates of 138 kg N/ha was economically optimal for the production of maize at Sibu Sire district (Table 3).

***Table 3.*** *Summary of partial budget analysis for economic fertilizer recommendation for maize production at Sibu Sire District.*

| N (kg/ha) | P (kg/ha) | AGY (Qt/ha) | GFB (ETB/ha) | FC (birr/ha) | TSC (birr/ha) | HBC (birr/ha) | TVC (birr/ha) | NB (birr/ha) | MRR (%) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 37.759 | 2454.52 | 0.00 | 1132.78 | 566.39 | 1699.17 | 22844.3 | |
| 0 | 10 | 51.50463 | 33478.01 | 645.74 | 1545.14 | 772.57 | 2963.44 | 30514.57 | 606.69 |
| 0 | 20 | 52.84722 | 34350.69 | 1291.47 | 1585.42 | 792.71 | 3669.60 | 3061.10 | 23.58 |
| 0 | 40 | 51.81481 | 33679.63 | 2582.94 | 1554.44 | 777.22 | 4914.61 | 28765.02 | -153.90 |
| 46 | 0 | 52.11111 | 33872.22 | 1348.25 | 1563.33 | 781.67 | 3693.25 | 30178.97 | -115.77 |
| 46 | 10 | 64.07407 | 41648.15 | 1993.99 | 1922.22 | 961.11 | 4877.32 | 36770.83 | 556.71 |
| 46 | 20 | 58.77778 | 38205.56 | 2639.72 | 1763.33 | 881.67 | 5284.72 | 32920.84 | -945.01 |
| 46 | 40 | 70.66667 | 45933.33 | 3931.19 | 2120.00 | 1018.06 | 7111.19 | 38822.14 | 323.10 |
| 92 | 0 | 61 | 39650.00 | 2696.50 | 1830.00 | 915.00 | 5441.50 | 34208.50 | 276.32 |
| 92 | 10 | 67.87037 | 44115.74 | 3342.24 | 2036.11 | 1018.06 | 6396.40 | 37719.34 | 367.66 |
| 92 | 20 | 77.74074 | 50531.67 | 3987.79 | 2332.22 | 1166.11 | 7486.30 | 40045.18 | 488.65 |
| 92 | 40 | 77.83333 | 50591.67 | 5279.44 | 2335.00 | 1167.50 | 8781.94 | 41809.73 | -95.35 |
| 138 | 0 | 60.94444 | 39613.89 | 4044.75 | 1828.33 | 914.17 | 6787.25 | 32826.64 | 450.35 |
| 138 | 10 | 78.24074 | 50856.48 | 4690.49 | 2347.22 | 1173.61 | 8211.32 | 40645.16 | 689.47 |
| 138 | 20 | 77.18519 | 50170.37 | 5336.22 | 2315.56 | 1157.78 | 8809.55 | 41960.82 | -214.69 |
| 138 | 40 | 82.77778 | 53805.56 | 6627.69 | 2483.33 | 1241.67 | 10352.69 | 40345.87 | 135.57 |

N= Nitrogen, P= Phosphorous, AGY= Average Grain Yield, GFB= growth field benefit FC=Fixed Cost, TVC = Total variable cost, NB= Net Benefit MRR=Marginal Rate Return

# 4. Conclusion and Recommendation

Application of different nitrogen and phosphorus fertilizer rates had significantly increased grain yield of maize. Phosphorous fertilizer application at an optimum level is necessary to improve the grain yield of maize. The results of the study revealed that the main effects of P fertilizer and its interaction with N fertilizer were significantly influenced the mean grain yield of maize in the Sibu Sire district. Partial budget analysis showed 138 kg/ha of N was economically optimal for the production of maize in the district. Phosphorus critical level (10 ppm) and requirement factor (20.63) were recommended for maize productions in the district. With these recommended values, the crop achieved about 80% of its maximal yield in the absence of P fertilizer application in the study area. Applying P above this level is the cost of additional P fertilizer to produce extra yield. Thus, in soils with available P status below 10 mg $kg^{-1}$, the yield of maize could show a significant response to applications of P fertilizers. Whereas in areas with soil available P status greater than 10 mg $kg^{-1}$, the P concentration in the soil sufficient crop growth so further addition of P fertilizer may not result in a profitable yield increase. In addition to this finding, other natural and organic fertilizers are essential to future yielg, maintenance, and sustainability of soil health and productivity. Thus, farmers in the area might be advised to use soil testing-based crop responses and phosphorus recommendations to increase the productivity of maize and optimize their maize yields. Future research should focus on verifying results on farmland before implementing the technology in real-district agriculture. By implementing these methods, farmers can effectively manage their soil fertility and make informed decisions about maximizing their maize yields.

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## Conflicts of Interest

The authors declare no conflicts of interest.

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