Temporal dynamics of chlorophyll indices in corn leaves in response to top-dressing with organo-mineral fertilizer

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Abstract.
Nitrogen is one of the main limiting factors for maize productivity, and managing it efficiently is fundamental for sustainable agriculture. Understanding how different nitrogen fertilization strategies affect plant physiological parameters throughout the crop cycle is essential for optimizing nutrient use efficiency. This study aimed to evaluate how chlorophyll indices (total, a, and b) in maize leaves vary throughout the cycle in response to different rates of organo-mineral fertilizer applied as a top-dressing. The experiment was conducted under sprinkler irrigation in a randomized block design with four replications. The hybrid Dekalb 390 Pro 4 was sown at a density of 70,000 plants per hectare with 0.5 m spacing between rows. Five top-dressing rates were tested: 0 (control), 75, 150, 225, and 300 kg/ha. Chlorophyll indices (SPAD values for total, a, and b chlorophyll) were measured with a Falker chlorophyll meter. Evaluations were conducted weekly from 10 to 107 days after sowing (DAS) on leaves C and C-1, with 30 leaves evaluated per plot in the middle third of the leaf blade. Data were analyzed using polynomial regression to describe how chlorophyll varied over time in each treatment. Results showed that a second-degree polynomial model (SPAD = a + bDAS + cDAS²) better described the temporal dynamics of chlorophyll in all treatments, with significant improvement compared to linear regression (ΔR^2 = 0.0574 to 0.1714). The 225 kg/ha rate showed the highest chlorophyll peak (61.35 SPAD at 41.9 DAS), while the 300 kg/ha rate had an earlier peak (59.10 SPAD at 16.8 DAS). The control reached its peak at 24.7 DAS (58.37 SPAD), showing that organo-mineral fertilization extended the chlorophyll accumulation period. The rate of chlorophyll decline at the end of the cycle varied among treatments, being faster at 300 kg/ha (-0.3705 SPAD/day) and slower at 225 kg/ha (-0.1847 SPAD/day), suggesting this rate better maintained photosynthetic capacity during

senescence. Top-dressing with organo-mineral fertilizer significantly influenced chlorophyll dynamics in maize, with the 225 kg/ha rate showing the best performance both in chlorophyll peak and in maintaining high levels until the end of the cycle. Polynomial regression analysis showed that chlorophyll response over time follows a parabolic pattern, well capturing the accumulation, peak, and decline phases. These results indicate that organo-mineral fertilizer releases nutrients gradually, compatible with maize nutrient uptake curve, being a promising technology to improve nutrient use efficiency and crop physiological performance.

Keywords.
SPAD, Chlorophyll, Crop monitoring, Sustainable agriculture, Nitrogen, Zea mays

Introduction

Nitrogen (N) is the nutrient most limiting to maize (*Zea mays* L.) productivity, playing a central role in the synthesis of chlorophyll, proteins, and enzymes associated with photosynthesis and grain filling (Gheith et al., 2022). As one of the most important cereal crops globally, maize is widely used for food, feed, and industrial purposes, and adequate nitrogen supply throughout the crop cycle is essential to sustain high leaf chlorophyll concentrations, which directly determine photosynthetic rates and, consequently, biomass accumulation and yield (Li et al., 2022).

Leaf chlorophyll content is widely used as a proxy for the photosynthetically active nitrogen pool, and its non-destructive assessment using portable chlorophyll meters (SPAD) enables real-time monitoring of plant nutritional status throughout the crop cycle (Shivashankar et al., 2025). The temporal dynamics of SPAD readings in maize follow a characteristic parabolic pattern, with an increase during vegetative growth, a peak near flowering, and a progressive decline during grain filling and senescence. Nitrogen application rates significantly affect both the maximum SPAD value (SPADmax) and the duration of high SPAD readings, making the temporal characterization of chlorophyll dynamics a valuable tool for evaluating fertilization strategies (Li et al., 2022).

Organo-mineral fertilizers, which combine organic and mineral nitrogen sources, have been proposed as an alternative to conventional mineral fertilizers due to their potential for slower, more synchronized nutrient release compatible with the maize nitrogen uptake curve. However, little information is available on how different rates of organo-mineral top-dressing influence the temporal pattern of chlorophyll accumulation and decline across the full maize cycle under irrigated conditions. The present study aimed to characterize the temporal dynamics of chlorophyll indices (total, a, and b) in maize leaves in response to five rates of organo-mineral fertilizer applied as top-dressing, using polynomial regression to model the accumulation, peak, and decline phases throughout the crop cycle.

Materials and Methods

The experiment was conducted under sprinkler irrigation in the state of Minas Gerais, Brazil, using a randomized complete block design with four replications. The maize hybrid Dekalb 390 Pro 4 was sown at a density of 70,000 plants per hectare with 0.50 m row spacing. Five organo-mineral fertilizer rates were applied as top-dressing: 0 (control), 75, 150, 225, and 300 kg/ha.

Chlorophyll indices (total chlorophyll, chlorophyll a, and chlorophyll b, expressed as SPAD values) were measured weekly from 10 to 107 days after sowing (DAS) using a Falker chlorophyll meter, on leaves C (first leaf with a visible collar) and C-1 (the leaf immediately preceding C). For each evaluation date, 30 leaves per plot were measured at the middle third of the leaf blade, and mean values per plot and per treatment were calculated.

Data were analyzed using polynomial regression to describe how chlorophyll indices varied over time within each treatment. Linear and second-degree polynomial models were fitted and compared based on the coefficient of determination (R^2) and the improvement in fit (delta R^2, Delta R^2). The polynomial model $SPAD = a + bDAS + cDAS^2$ was selected as the primary

analytical framework, with model parameters used to estimate the DAS of peak chlorophyll (vertex of the parabola) and the rate of chlorophyll decline in the post-peak phase.

Results and Discussion

The second-degree polynomial model provided a significantly better fit than linear regression for describing the temporal dynamics of chlorophyll in all treatments, with improvements in R^2 (Delta R^2) ranging from 0.0574 to 0.1714 across chlorophyll fractions and nitrogen rates. This parabolic behavior reflects the well-documented pattern of chlorophyll accumulation during vegetative growth, peak near the flowering stage, and progressive decline during grain filling and senescence in maize (Li *et al.*, 2022; Shivashankar *et al.*, 2025). Table 1 summarizes the key parameters of the fitted polynomial models for total chlorophyll across all treatments.

Table 1. Polynomial regression parameters for total chlorophyll (SPAD) dynamics in maize under different organo-mineral fertilizer rates.

Rate (kg/ha)	a	b	Peak SPAD (DAS)	Decline rate (SPAD/day)
0 (control)	55.7820	0.2097	24.7 (58.37)	0.2933
75	56.3431	0.2370	26.4 (59.48)	0.2973
150	51.4309	0.4386	38.7 (59.92)	0.2332
225	52.0306	0.4449	41.9 (61.35)	0.1847
300	57.8636	0.1470	16.8 (59.10)	0.3705

Note: Peak SPAD value shown in parentheses. a = intercept; b = linear coefficient of the polynomial model SPAD = a + bDAS + cDAS²; DAS = days after sowing.

The 225 kg/ha rate achieved the highest chlorophyll peak (61.35 SPAD at 41.9 DAS), the latest timing of peak accumulation, and the slowest post-peak decline rate (0.1847 SPAD/day), indicating superior maintenance of photosynthetic capacity throughout the productive cycle. In contrast, the 300 kg/ha rate showed an earlier and lower peak (59.10 SPAD at 16.8 DAS) and the fastest post-peak decline (0.3705 SPAD/day), suggesting that excessive nitrogen rates may accelerate senescence rather than sustaining chlorophyll content. The control treatment peaked at 24.7 DAS (58.37 SPAD), demonstrating that organo-mineral fertilization effectively extended the chlorophyll accumulation period relative to the unfertilized treatment.

These results are consistent with the findings of Li et al. (2022), who demonstrated that nitrogen application rates significantly affect SPADmax and the duration of high SPAD readings in maize, with nitrogen-deficient plants showing shorter high-SPAD periods and more rapid senescence of lower leaves. The parabolic temporal pattern observed across all treatments in the present study also aligns with the spatiotemporal SPAD dynamics reported by Shivashankar et al. (2025), reinforcing the robustness of polynomial models for characterizing chlorophyll dynamics under varying nitrogen supply.

The differential chlorophyll dynamics observed between the 225 and 300 kg/ha rates suggest that the gradual nutrient release profile of the organo-mineral fertilizer is better synchronized with the maize nitrogen uptake curve at intermediate rates, avoiding early-season luxury nitrogen consumption and the associated acceleration of senescence at the end of the cycle. This compatibility between the nutrient release pattern of the organo-mineral fertilizer and the physiological demand of the crop represents a key advantage over conventional mineral sources, which may supply nitrogen at rates exceeding plant uptake capacity, leading to losses and reduced nitrogen use efficiency (Gheith et al., 2022).

Conclusion

Top-dressing with organo-mineral fertilizer significantly influenced the temporal dynamics of chlorophyll indices in maize leaves. The second-degree polynomial model adequately

described the accumulation, peak, and decline phases of chlorophyll throughout the cycle in all treatments. The 225 kg/ha rate demonstrated the best overall performance, achieving the highest chlorophyll peak (61.35 SPAD at 41.9 DAS) and the slowest post-peak decline rate (0.1847 SPAD/day), indicating superior maintenance of photosynthetic capacity through senescence. These results suggest that organo-mineral fertilizers release nutrients in a pattern compatible with the maize nitrogen uptake curve, representing a promising strategy for improving nitrogen use efficiency and crop physiological performance under irrigated conditions.

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