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Dynamics of plastid pigments in sweet corn leaves under different fertilization regimes and heat stress

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Abstract: The objective of this study was to evaluate the residual effects of three fertilization regimes on the content and dynamics of plastid pigments in sweet corn leaves (*Zea mays var. saccharata* ‘Overland F1’) grown under abiotic stress conditions. A randomized complete block design with four replications was established with the following treatments: T1 – unfertilized control; T2 Organic fertilization – Fertisol (NPK 4:3:3 + 1.3% MgO и 62% OM); T3 Mineral fertilization – $N_{15}K_{15}P_{15}$; T4. Combined fertilization – Fertisol + $N_{15}K_{15}P_{15}$. Chlorophyll a, chlorophyll b, and β-carotene were measured at two growth stages: vegetative (V8–V9) and reproductive (Milk stage). At the first measurement, maximum values of total chlorophyll (3.02 mg g^{-1}), chlorophyll a (1.88 mg g^{-1}), and chlorophyll b (1.14 mg g^{-1}) were recorded in treatment T3 (mineral fertilization), while the lowest values were observed under organic fertilization (T2: 1.26 mg g^{-1} and 0.82 mg g^{-1}). During the reproductive stage, total chlorophyll content decreased in all treatments except T4 (combined), where chlorophyll a increased from 1.26 to 1.83 mg g^{-1} (+15.4%) and the Chl a/b ratio increased to 3.40, likely due to delayed pigment degradation and extended green period. These results demonstrate that the integrated organic-mineral approach can optimize plant nutrition by combining the rapid action of mineral fertilizers with the prolonged effect of organic sources. This leads to extended photosynthetic activity and enhanced yield potential under changing climate conditions.

Key words: sweet corn leaves; chlorophyll; β-carotene; Fertisol; mineral fertilization; integrated fertilization

INTRODUCTION

Chlorophyll is a key pigment in plant tissues, determining their photosynthetic capacity. Leaf chlorophyll content is widely used as an indicator of crop physiological status, including in sweet corn (*Zea mays L.*) (Yin et al., 2023; Muhammad et al., 2022). Chlorophyll levels are influenced by plant access to macronutrients, particularly nitrogen, which, as a core component of the chlorophyll molecule, directly affects growth, productivity, and photosynthetic efficiency (Li et al., 2012; Thapa et al., 2024). Several studies have shown that optimal nitrogen fertilization increases leaf chlorophyll concentration, enhances photosynthetic activity, and improves maize yield, whereas nitrogen deficiency constrains these processes (Li et al., 2012; Muhammad et al., 2022; Thapa et al., 2024). Therefore, chlorophyll content is frequently used as a proxy for photosynthetic activity, plant nitrogen status, or potential deficiency (Costache et al., 2012; Bakhshande Larimi et al., 2014).

Temperature anomalies – both high and low – adversely affect plant physiology, accelerating chlorophyll degradation and reducing leaf light-harvesting capacity. This leads to slowed growth and decreased final yield (Wu et al., 2022;

Djalovic et al., 2024). It has been demonstrated that under stress conditions, nitrogen fertilization can mitigate the negative impacts of extreme temperatures by maintaining higher chlorophyll levels and enhancing recovery processes in the leaves (Muhammad et al., 2022; Chibane et al., 2024; Thapa et al., 2024). These interactions underpin numerous fertilization and management recommendations aimed at sustainable sweet corn production under contemporary climate challenges.

The objective of this study was to assess the residual effect of different fertilization regimes on the content and dynamics of plastid pigments in sweet corn leaves grown under abiotic stress conditions.

MATERIALS AND METHODS

A field experiment with sweet corn (*Zea mays var. saccharata* 'Overland F1') was conducted at the "Tsalapitsa" research station of ISSAPP "Nikola Pushkarov" under drip-irrigated conditions. The trial followed a common bean precursor as part of a long-term fertilization study. The 2024 growing season was characterized by severe drought and elevated temperatures. From April to August, average monthly temperatures exceeded the multi-year norm by 3.8-5.6 °C, and cumulative rainfall totaled only 122 mm (norm 253 mm), with virtually no precipitation in June and July (Figure 1). Mean relative humidity fell to approximately 50% during the peak period of crop development.

The experiment was laid out in a randomized block design with four replications and four fertilization treatments: T1 – control (no fertilization); T2 – organic fertilization (1 t ha^{-1} Fertisol, Komeco); T3 – mineral fertilization (266 kg ha^{-1} $N_{15}K_{15}P_{15}$); T4 – integrated fertilization (500 kg ha^{-1} Fertisol + 133 kg ha^{-1} $N_{15}K_{15}P_{15}$). The organic treatment used pelleted composted manure (NPK 4:3:3 + 1.3% MgO, 62% organic matter), and the mineral treatment used a standard NPK 15:15:15 formulation. All fertilizers were applied in 2023, and their residual effects were evaluated in 2024.

The soil at the trial site is an alluvial meadow Fluvisol (FAO, ISRIC World Soils) with neutral pH (7.1) and low humus content (1.40%). Prior to trial establishment, soil samples were collected at 0-30 cm depth (Figure 2) for each treatment, and analyzed by standard methods for pH, total nitrogen (Bremner and Keeney, 1965), and P_2O_5 and K_2O in lactate extract (Ivanov, 1984).

Leaf pigment content was measured at two growth stages: vegetative (V8–V9) and reproductive (Milk stage) (Hanway, 1966; Abendroth et al., 2011). Plastid pigments were quantified spectrophotometrically using an Agilent Cary 60

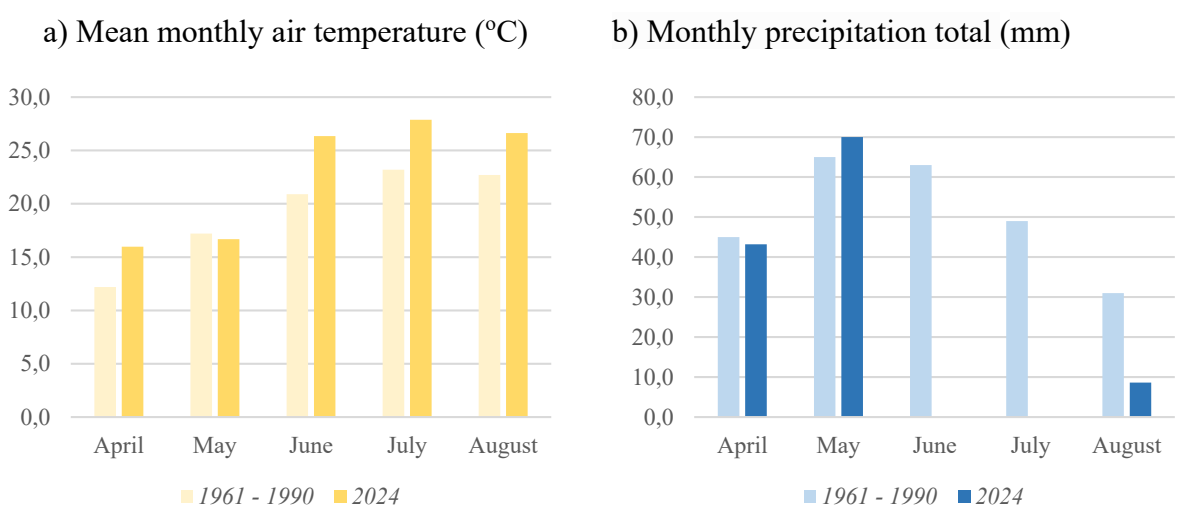


Figure 1. Dynamics of temperature and precipitation during the vegetation period of sweet corn

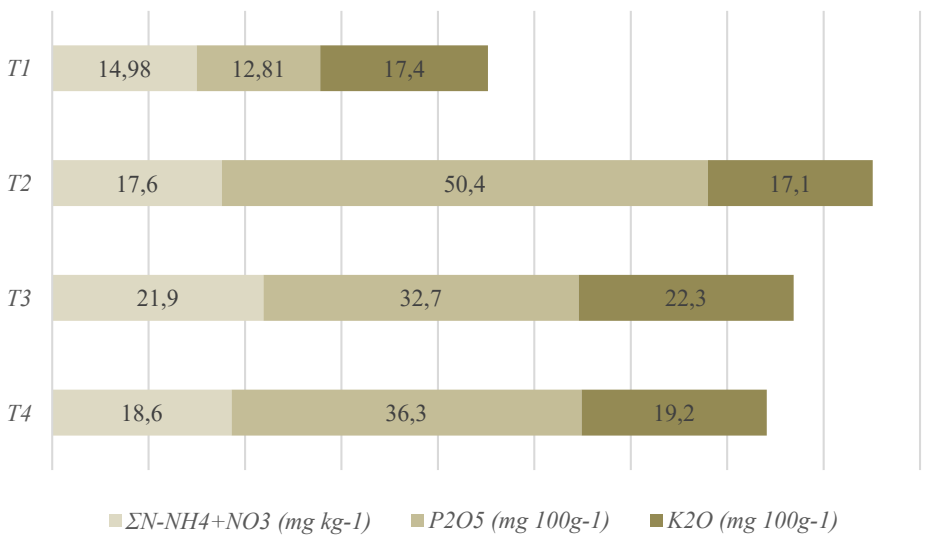
fiber-optic spectrophotometer according to Lichtenthaler and Wellburn (1985). Data processing and graph production were performed in Microsoft Excel Professional Plus (version 2020, Microsoft Corporation).

RESULTS AND DISCUSSION

Soil analysis prior to experiment establishment reflected the residual effects of fertilization from the previous legume crop, with soil macronutrient levels varying significantly according to the fertilizer type (Figure 2). Treatment T3 (mineral fertilization) exhibited the highest total nitrogen and potassium concentrations, whereas the greatest phosphorus content was observed in T2 (organic fertilization). This likely results from the N:P ratio and the large application rate of the organic fertilizer, which promoted P_2O_5 accumulation, as well as enhanced phosphorus mineralization and mobilization by organic amendments (Shi et al., 2024; Li et al., 2024).

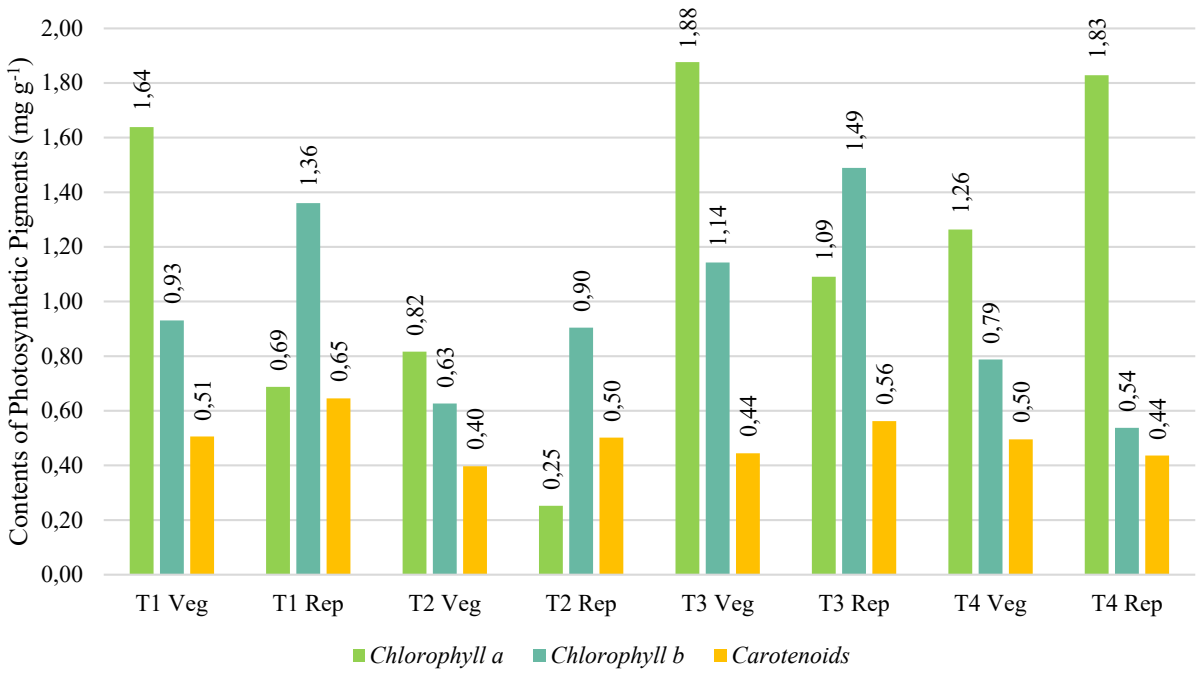
Substantial variation in plastid pigment content mirrored natural leaf senescence, heat stress, and fertilization effects. At the first sampling (vegetative phase, coinciding with the onset of temperature anomalies), pronounced differences in chlorophyll content were evident (Figure 3; Table 1). Treatment T3 recorded the highest values of total chlorophyll (3.02 mg g^{-1}), chlorophyll a (1.88 mg g^{-1}), and chlorophyll b (1.14 mg g^{-1}), consistent with the rapid nutrient availability provided by mineral fertilizers, especially nitrogen and potassium. The lowest pigment levels occurred in T2, likely due to slower nitrogen release from the organic source. Previous studies note that organic fertilizers supply nutrients gradually, while mineral fertilizers deliver immediate availability during critical early growth stages (Lal, 2020; Allam et al., 2022; Zhang et al., 2023). Carotenoid content remained relatively stable across treatments (0.40-0.51 mg g^{-1}), underscoring their role in antioxidant protection under initial stress.

Correlation analysis between soil macronutrients and pigment contents at the first sampling revealed moderate positive correlation of total soil nitrogen with chlorophyll (r = 0.381), strongest with chlorophyll b (r = 0.492) (Figure 4; Table 2). Treatment T3, with the highest soil nitrogen (21.90 mg g^{-1}), corresponded to maximal chlorophyll levels (3.02 mg g^{-1}). In T2, despite relatively high soil nitrogen (17.60 mg g^{-1}), chlorophyll was lowest, likely reflecting delayed mineralization



** T1. Control – No fertilization treatment; T2. Organic fertilization – Fertisol; T3. Mineral fertilization – $N_{15}K_{15}P_{15}$; T4. Integrated fertilization – Fertisol + $N_{15}K_{15}P_{15}$.*

Figure 2. Soil analysis prior to experiment setup



** T1. Control – No fertilization treatment; T2. Organic fertilization – Fertisol; T3. Mineral fertilization – $N_{15}K_{15}P_{15}$; T4. Integrated fertilization – Fertisol + $N_{15}K_{15}P_{15}$.*

Figure 3. Changes in leaf pigment content between vegetative and reproductive stages of sweet corn under different fertilization treatments

Table 1. Total chlorophyll concentration and Chlorophyll a/b ratio across vegetative and reproductive stages

	Vegetative Stage		Reproductive Stage	
	Chlorophyll a+b mg g^{-1}	Chlorophyll a/b	Chlorophyll a+b	Chlorophyll a/b
T1	2.57	1.76	2.05	0.51
T2	1.44	1.30	1.16	0.28
T3	3.02	1.64	2.58	0.73
T4	2.05	1.60	2.37	3.40

** T1. Control – No fertilization treatment; T2. Organic fertilization – Fertisol; T3. Mineral fertilization – $N_{15}K_{15}P_{15}$; T4. Integrated fertilization – Fertisol + $N_{15}K_{15}P_{15}$.*

under heat stress (Szulc et al., 2012; Pangaribuan et al., 2018). These findings confirm nitrogen's role in chlorophyll synthesis but indicate that under thermal stress, other factors (e.g., soil K_2O) may become limiting (Li et al., 2024).

The critical function of potassium in maintaining leaf turgor, stomatal regulation (in *Solanaceae*), and activation of over 60 enzymes, including those for chlorophyll synthesis, is well established (Ma et al., 2022; Li et al., 2024). In this study, soil potassium showed strong positive correlations with chlorophyll a, chlorophyll b, and total chlorophyll (r = 0.68-0.80) (Figure 5; Table 2), highlighting its importance for the photosynthetic apparatus under stress.

Of particular interest is the plant response to high soil phosphorus in treatment T2, which exhibited the lowest pigment levels (Figure 3) and

Table 2. Correlation between soil total nitrogen, phosphorus, and potassium and leaf pigment contents

	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Carotenoids
Total N	0.325	0.492	0.381	-0.361
P_2O_5	-0.722	-0.570	-0.677	-
K_2O	0.685	0.796	0.724	-

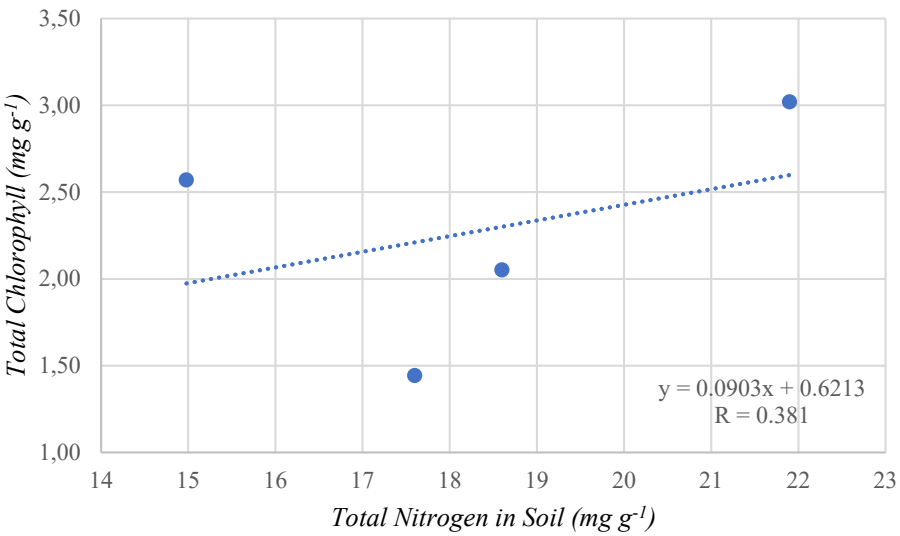


Figure 4. Relationship between Soil Total Nitrogen and Chlorophyll Content at Vegetative Stage

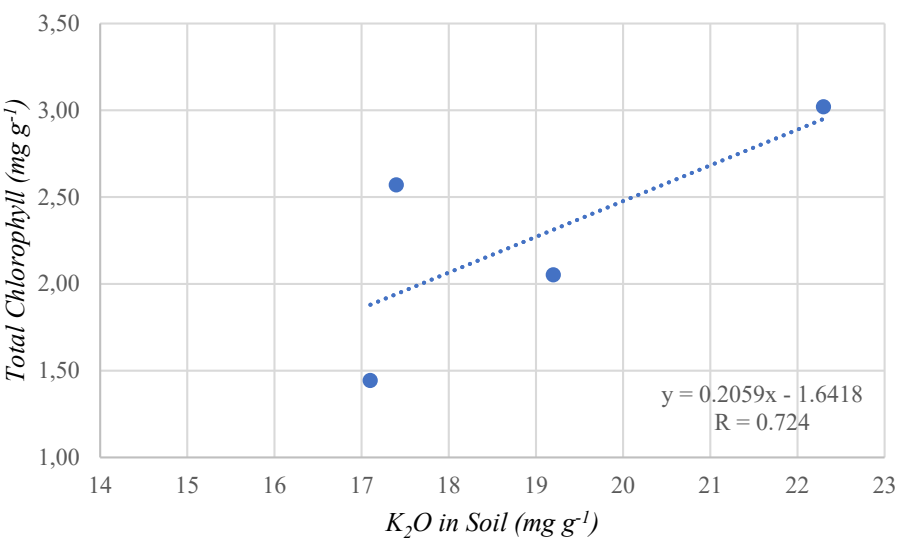


Figure 5. Relationship between Soil K_2O and Chlorophyll Content at Vegetative Stage

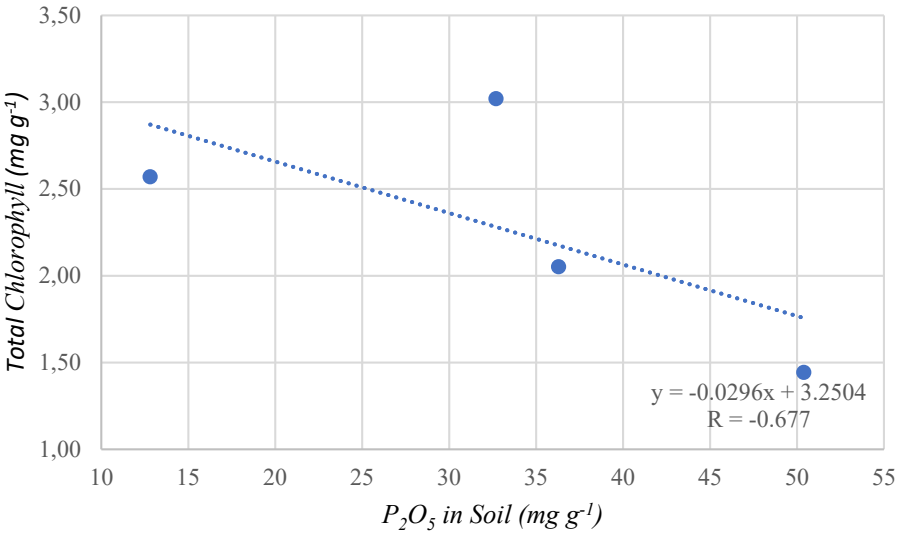


Figure 6. Relationship between Soil P_2O_5 and Chlorophyll Content at Vegetative Stage

negative correlation (Figure 6, Table 2). Similar results have been reported by Hernández & Munné-Bosch (2015), Wu et al. (2019), and Li et al. (2022), who observed adverse effects of excess phosphorus on chlorophyll synthesis and stability, particularly under stress conditions such as high temperatures. Excessive soil phosphorus accumulation can inhibit the transport and uptake of micronutrients such as iron and magnesium, which are essential for chlorophyll synthesis. Jindo et al. (2023) and Shi et al. (2024) also associate reduced pigment synthesis with high P_2O_5 concentrations from organic fertilizer applications.

Comparing results from the second sampling at the reproductive phase – after nearly two months under intensive heat stress and drought – clear changes in leaf plastid pigment content are evident relative to the initial vegetative measurements (Figure 3).

Our data confirmed direct influence of soil macronutrient availability on plastid pigment content. Treatments with superior soil characteristics maintained the highest chlorophyll a and b concentrations, preserving photosynthetic potential and delaying leaf senescence, which is critical for maximum biomass accumulation and yield potential in sweet corn (Figures 1, 2). Under mineral fertilization (T3), the trend for highest total chlorophyll levels persisted (2.58 mg g^{-1}). Most treatments showed decreases in total chlorophyll relative to the first sampling, with the greatest losses in the control (20.3%), followed by T2 (19.8%) and T3 (14.6%). This can be explained by accelerated photosynthetic pigment degradation due to leaf senescence and cumulative heat stress (Hörtensteiner & Kräutler, 2000; Kandel, 2020). In contrast, integrated fertilization (T4) showed an increase exceeding 15% (from 1.26 to 1.83 mg g^{-1}). This represents an interesting anomaly that contradicts expected physiological processes during leaf senescence, where chlorophyll a typically degrades more rapidly (Szulc et al., 2012; Hussain et al., 2019; Qu et al., 2023). This phenomenon may be explained by the delayed, prolonged effects of the organic component on nitrogen nutrition (Diacono & Montemurro, 2010; Yao et al., 2021).

Chlorophyll b exhibited an inverse trend, increasing in almost all treatments (Figure 3), with the greatest accumulation recorded in the control (0.43 mg g^{-1}). Treatment T4 was again an exception, showing a decrease of 0.25 mg g^{-1}, in contrast to the increase in chlorophyll a.

Carotenoid levels at the end of the period increased slightly or remained stable across near-

ly all treatments (0.40-0.57 mg g^{-1}), confirming their greater resistance to degradation. Such an increase may represent a response to escalating heat stress and photooxidative damage (Pangaribuan et al., 2018; Qu et al., 2023; Pérez-Molina et al., 2020).

Photosynthetic system activity is characterized by the Chl a/b ratio, which varies with growing conditions and developmental stage (Katayama & Shida, 1970). For sweet corn, a C4 crop, optimal values are reported between 3.3 and 4.5. As vegetative growth progresses, during senescence or under various stress conditions, the Chl a/b ratio often decreases to approximately 2 and can sometimes fall below 1 (Lichtenthaler & Babani, 2021; Yan et al., 2021). In this study, the calculated Chl a/b ratios for treatments T1, T2, and T3 were significantly lower (Table 1), despite absolute chlorophyll a and b values falling within literature ranges (Szulc et al., 2012; Pangaribuan et al., 2018; Pan et al., 2024). Low Chl a/b values were mainly due to relatively higher chlorophyll b content, likely reflecting a physiological adaptation to stress. This leads to an expansion of the light-harvesting complexes (LHC) of Photosystem II or to alterations in chloroplast structure. Under stress conditions, Chl a/b reduction may occur despite maintaining pigment concentrations within normal ranges (Sarhadi et al., 2020; Stefanov et al., 2023). Additionally, leaf senescence accelerates chlorophyll a degradation relative to chlorophyll b, further lowering the ratio (Lichtenthaler & Babani, 2021; Stefanov et al., 2023).

The dynamics of the Chl a/b ratio in the integrated fertilization treatment (T4) were the opposite, exhibiting a sharp increase to 3.40, likely resulting from an adaptive physiological response or alterations in chlorophyll–protein complex structure under mixed fertilization. This anomaly may be interpreted as a potential "stay-green" phenomenon or as a consequence of prolonged nitrogen release from organic components and sustained chlorophyll a synthesis (Iqbal et al., 2021; Lichtenthaler & Babani, 2021; Stefanov et al., 2023; Chibane et al., 2024). According to Yao et al. (2021), combining organic and mineral sources can enhance maize resilience to abiotic stress by maintaining photosynthetic activity. These results highlight the importance of achieving balanced nutrient supply and implementing precise fertilization strategies to meet contemporary agricultural demands.

CONCLUSIONS

The fertilization regime exerts a critical influence on the content and stability of photosynthetic pigments in sweet corn under heat stress. The integrated system combines the advantages of organic and mineral approaches, extending the "green" phase through delayed chlorophyll a degradation and maintaining photosynthetic activity under stress conditions. This strategy optimizes the balance between rapid nutrient availability and long-term supply, which may enhance yield and resilience of corn under extreme climatic conditions.

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REFERENCES

Allam, M., Radicetti, E., Quintarelli, V., Petroselli, V., Marinari, S., & Mancinelli, R. (2022). Influence of organic and mineral fertilizers on soil organic carbon and crop productivity under different tillage systems: a meta-analysis. *Agriculture, 12*(4): 464.
https://doi.org/10.3390/agriculture12040464.

Bakhshande Larimi S., Shakiba, M., Mohamadinasab, A., & Moghadam, M. (2014). Changes in nitrogen and chlorophyll density and leaf area of sweet basil (*Ocimum basilicum L.*) affected by Biofertilizer and nitrogen application. *International Journal of Biosciences (JIB), 5*(9): 256-265.

Bremner, J., & Keeney, D. (1965). Steam distillation methods for determination of ammonium, nitrate, and nitrite. *Analytica Chimica Acta, 32*: 485-495.

Chibane, N., Revilla, P., Yannam, V., Marcet, P., Covelo, E., & Ordás, B. (2024). Impact of irrigation,

nitrogen fertilization, and plant density on stay-green and its effects on agronomic traits in maize. *Frontiers in Plant Science, 15*, 1399072.
https://doi.org/10.3389/fpls.2024.1399072.

Costache, M., Campeanu, G., & Neata, G. (2012). Studies concerning the extraction of chlorophyll and total carotenoids from vegetables, *Romanian Biotechnological Letters, 17*(5), 7702-7708.

Diacono, M., & Montemurro, F. (2010). Long-term effects of organic amendments on soil fertility. A review. *Agronomy for Sustainable Development, 30*, 401-422.
https://doi.org/10.1051/agro/2009040.

Djalovic, I., Kundu, S., Bahuguna, R., Pareek, A., Raza, A., Singla-Pareek, S., Prasad, P., & Varshney, R. (2024). Maize and heat stress: Physiological, genetic, and molecular insights. *The Plant Genome, 17*, e20378. https://doi.org/10.1002/tpg2.20378.

Hernández, J., & Munné-Bosch, S. (2015). The role of phosphorus in plant growth, development, and stress responses. *Plant Physiology and Biochemistry, 86*, 112-124.
https://doi.org/10.1016/j.plaphy.2015.09.005.

Hörtensteiner, S., & Kräutler, B. (2000). Chlorophyll degradation during senescence. *Annual Review of Plant Physiology and Plant Molecular Biology, 51*, 323-353.
https://doi.org/10.1146/annurev.arplant.51.1.323.

Hussain, H., Men, S., Hussain, S., Chen, Y., Ali, S., Zhang, S., Zhang, K., Li, Y., Xu, Q., Liao, C., & Wang, L. (2019). Interactive effects of drought and heat stresses on morpho-physiological attributes, yield, nutrient uptake and oxidative status in maize hybrids. *Scientific Reports, 9*, 3890. https://doi.org/10.1038/s41598-019-40362-7.

Iqbal, A., He, L., Ali, I., Ullah, S., Khan, A., Akhtar, K., Wei, S., Fahad, S., Khan, R., & Jiang, L. (2021). Co-incorporation of manure and inorganic fertilizer improves leaf physiological traits, rice production and soil functionality in a paddy field. *Scientific reports, 11*, 10048. https://doi.org/10.1038/s41598-021-89246-9.

Ivanov, P. (1984). A new acetate-lactate method for determining plant-available phosphorus and potassium in soil. *Soil Science and Agrochemistry, 4*, 88-98 (BG).

Kandel, B. (2020). SPAD value varies with age and leaf of maize plant and its relationship with grain yield. *BMC Research Notes, 13*, 475. https://doi.org/10.1186/s13104-020-05324-7.

Katayama, Y., & Shida, S. (1970). Studies on the Change of Chlorophyll a and b Contents Due to Projected Materials and Some Environmental Conditions, *Cytologia, 35*(2): 171-180.

Lal, R. (2020). Regenerative agriculture for food and climate. *Journal of Soil and Water Conservation, 75*(5), 123-124. https://doi.org/10.2489/jswc.2020.0620A.

Li, F., Zhang, S., Chai, L., Guo, Z., Li, P., Han, Y., & Wang, Y. (2024). Enhanced maize yield and nitrogen efficiency with low molecular weight fulvic acid: insights into chlorophyll a/b ratio and nitrogen metabolising enzyme activity. *Plant, Soil and Environment, 70*(10), 632-643. https://doi.org/10.17221/320/2024-PSE.

Li, G., Zhang, Z., Gao, H., Liu, P., Dong, S., Zhang, J., & Zhao, B. (2012). Effects of nitrogen on photosynthetic characteristics of leaves from two different stay-green corn (*Zea mays L.*) varieties at the grain-filling stage. *Canadian Journal of Plant Science. 92*(4), 671-680. https://doi.org/10.4141/cjps2012-039.

Li, X., Hallama, M., & Romanya, J. (2024). Crops use inorganic and labile organic phosphorus from both high- and low-availability layers in no-till compost-amended soils. *Soil Use and Management, 40*(1): e13027. https://doi.org/10.1111/sum.13027.

Li, Z., Shao, G., & Guo, P. (2022). Excess phosphorus induces chlorophyll degradation and photosynthetic inhibition in maize (*Zea mays L.*) leaves. *Plant Physiology and Biochemistry, 169*, 109-117. https://doi.org/10.1016/j.plaphy.2021.11.012.

Lichtenthaler, H., & Babani, F. (2021). Contents of photosynthetic pigments and ratios of chlorophyll a/b and chlorophylls to carotenoids (a+b)/(x+c) in C4 plants as compared to C3 plants. *Photosynthetica, 60*(1), 3–9. https://doi.org/10.32615/ps.2021.041.

Lichtenthaler, H., & Wellburn, A. (1985). Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. *Biochemical Society Transactions, 11*, 591-592.

Ma, X., Cai, F., Mu, X., Li, H., Shao, R., Li, S., Xu, J., Wang, S., Lu, L., Zhao, X., Zhao, Y., & Liu, T. (2022). Effects of nitrogen application rate on photosynthetic physiology of maize leaves and yield under high temperature stress at ear stage. *Journal of Plant Nutrition and Fertilizers, 28*(10): 1852-1866. https://doi.org/10.11674/zwyf.2022035.

Muhammad, I., Yang, L., Ahmad, S., Farooq, S., Al-Ghamdi, A. A., Khan, A., Zeeshan, M., Elshikh, M. S., Abbasi, A. M., & Zhou, X. (2022). Nitrogen Fertilizer Modulates Plant Growth, Chlorophyll Pigments and Enzymatic Activities under Different Irrigation Regimes. *Agronomy, 12*(4), 845. https://doi.org/10.3390/agronomy12040845.

Pan, W., Cheng, X., Du, R., Zhu, X., & Guo, W. (2024). Detection of chlorophyll content based on optical properties of maize leaves. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 309*, 123843. https://doi.org/10.1016/j.saa.2024.123843.

Pangaribuan, D., Hendarto, K., Elzhivago, S., & Yulistiani, A. (2018). The effect of organic fertilizer and urea fertilizer on growth, yield and quality of sweet corn and soil health. *Asian Journal of Agriculture and Biology, 6*(3), 335-344.

Pérez-Molina, J., Lara, R., Brenes, I., Trejos, V., & Traña, A. (2020). Chlorophyll fluorescence and biomass partitioning within light and nitrogen deficiency: An example of the use of the R programming language for teaching. *UNED Research Journal, 12*, 2629. https://doi.org/10.22458/urj.v12i1.2629.

Qu, L., Gu, X., Li, J., Guo, J., & Lu, D. (2023). Leaf photosynthetic characteristics of waxy maize in response to different degrees of heat stress during grain filling. *BMC plant biology, 23*(1), 469. https://doi.org/10.1186/s12870-023-04482-7.

Sarhadi, H., Daneshian, J., Valadabadi, S., Sharafabad, H., & Afsharmanesh, G. (2020). The effect of drought stress and nitrogen fertilization on the active ingredient, chlorophyll A and B, and chlorophyll index of henna. *Nexo Revista Científica, 33*(02), 694-706. https://doi.org/10.5377/nexo.v33i02.10802.

Shi, X., Gu, D., Yang, H., Li, Y., Jiang, Y., Zhan, N., & Cui, X. (2024). Effect of exogenous organic matter on phosphorus forms in middle-high fertility Cinnamon soil. *Plants (Basel), 13*(10), 1313. https://doi.org/10.3390/plants13101313.

Stefanov, M., Rashkov, G., Borisova, P., & Apostolova, E. (2023). Sensitivity of the Photosynthetic Apparatus in Maize and Sorghum under Different Drought Levels. *Plants (Basel), 12*(9), 1863. https://doi.org/10.3390/plants12091863.

Szulc, P., Bocianowski, J., & Rybus-Zajac, M. (2012). The effect of soil supplementation with nitrogen and elemental sulphur on chlorophyll content and grain yield of maize (*Zea mays L.*). *Žemdirbystė=Agriculture, 99*(3), 247-254.

Thapa, B., Awal, R., Fares, A., Veettil, A., Elhassan, A., Rahman, A., Melaku, N., & Woldesenbet, S. (2024). Positive Sweet Corn Response with Selected Climate-Smart Agricultural Practices. *Agrosystems, Geosciences & Environment, 7*, e70011. https://doi.org/10.1002/agg2.70011.

Wu, J., Nadeem, M., Galagedara, L., Thomas, R., & Cheema, M. (2022). Effects of Chilling Stress on Morphological, Physiological, and Biochemical Attributes of Silage Corn Genotypes during Seedling Establishment. *Plants (Basel), 11*(9), 1217. https://doi.org/10.3390/plants11091217.

Wu, P., Ma, L., Hou, X., Wang, M., Wu, Y., Liu, F., & Deng, X. (2019). Phosphate transport and signaling in higher plants. *Annual Review of Plant Biology, 70*, 343-368. https://doi.org/10.1146/annurev-arplant-050718-100334.

Yan, Y., Hou, P., Duan, F., Niu, L., Dai, T., Wang, K., Zhao, M., Li, S., & Zhou, W. (2021). Improving photosynthesis to increase grain yield potential: an analysis of maize hybrids released in different years in China. *Photosynthesis research, 150*(1-3), 295-311. https://doi.org/10.1007/s11120-021-00847-x.

Yao, Z., Xia, Y., Zhang, J., & He, Y. (2021). Effects of organic and inorganic fertilization on chlorophyll content and yield of maize under drought stress. *Journal of Plant Nutrition, 44*(3), 382-393.

Yin, Y., Xinwen Xu, Z., Jia, M., Warner, T., Wang, X., Li, T., Cheng, T., Zhu, Y., Cao, W., & Yao, X. (2023). Tracing the nitrogen nutrient status of crop based on solar-induced chlorophyll fluorescence, *European Journal of Agronomy, 149*, 126924. https://doi.org/10.1016/j.eja.2023.126924.

Zhang, X., Davidson, E., Mauzerall, D., Searchinger, T., Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature, 528*, 51-59. https://doi.org/10.1038/nature15743.

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