ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2710-6012 (Online)
CODEN: JWBMAO

Journal of Wastes and Biomass Management (JWBM)

DOI: http://doi.org/10.26480/jwbm.01.2026.50.53

CrossMark

RESEARCH ARTICLE

MAIZE BIOMASS AND YIELD RESPONSES TO NITROGEN (N) AND PHOSPHORUS (P) APPLICATION

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ARTICLE DETAILS

Article History:

Received 26 March 2026
Revised 20 April 2026
Accepted 25 Mac 2026
Available online 10 June 2026

ABSTRACT

This study assessed the maize biomass yield and grain responses to different N and P levels at the University of Venda, Vhembe district, Limpopo province. The study was a 2x2 factorial, laid out in a completely randomised block design with 3 replications. N was applied at two levels: N0 = 0 kg ha^{-1} and N1= 75 kg ha^{-1}, while P was applied at P = 0 kg ha^{-1} and 30 kg ha^{-1}. For N, limestone ammonium nitrate (LAN 28% N) was used, while single super phosphate (SSP 10.5% P) was used for P. The results showed that both maize biomass and grain yield were significantly higher in the second growing season compared to the first, due to the alignment with high rainfall months. Combined N and P application consistently resulted in higher biomass and grain yields compared to standalone treatments or the control in both seasons. Specifically, grain yields were improved by the synergistic effect of N and P, although N-only applications resulted in slightly higher yields than P-only applications, indicating that N is the primary limiting nutrient in the study area. While P-only treatments were often limited by energy transfer inefficiencies, the balanced application of both nutrients optimised resource accumulation and cell division. The study concludes that strategic, balanced fertilisation is essential for improving maize productivity and food security for resource-poor smallholder farmers operating in nutrient-poor, rain-dependent environments.

KEYWORDS

crop productivity, soil fertility, soil amendment, grain, inorganic fertiliser.

1. INTRODUCTION

Soil fertility decline is a major constraint to crop production in South Africa (SA) (Sindesi et al., 2025a). Soil fertility decline in arable cropping land are predominantly ameliorated with the use of inorganic fertilisers, which include the use of nitrogen (N), phosphorus (P) and potassium (K) based fertilisers (Ghaffari Nejad et al., 2025). Nevertheless, the excessive use of N and P fertilisers leads to a further decline in soil fertility and the eutrophication of water, triggering harmful algal blooms such as cyanobacteria (Zhang et al., 2025a). N is essential for the vegetative growth of crops, while P assists in root development, thereby improving nutrient and other resource assimilation through the soil (Sindesi et al., 2025b; Mashece et al., 2025). N and P are the two most important limiting nutrients in maize production, influencing both maize biomass and grain yields (Ma et al., 2025). In SA, maize (Zea mays L.) is predominantly cultivated in nutrient-poor soils, thereby requiring the supplementation of nutrients through inorganic fertilisers (Haarhoff et al., 2020).

In SA, maize is an important staple crop, occupying approximately 46% of the total cultivated crop land (Haarhoff et al., 2020; Bradshaw et al., 2022). Maize is considered one of the important dryland crops in Limpopo province, with about 519 000 farmers producing it. Most of the rural population in the province consumes maize as their staple food (BFAP, 2016). Regardless of the uneven distribution and rainfall patterns, maize continues to be the main grain crop produced in large parts of the province (BFAP, 2016; Louis and Mathew, 2020). However, most of the farmers producing maize are small-scale farmers majority of whom are resource-poor; their cropping system has contributed to a reduction in soil fertility, especially N and P. Maize is highly grown for its multipurpose importance. It is cultivated as a source of food, animal feed, or raw material for the renewable energy, food and beverage industry (Kamusoko and Mukumba, 2025).

Maize biomass (leaves, stalks, cobs, and husks) is an important component in the rural provinces of SA, as it is used as livestock feed or grazing material by resource-poor communal and smallholder mixed farmers (Rusinamhodzi et al., 2015). In recent years, it has also been used as a raw material to produce biogas and diesel (Herrmann, 2013; Kamusoko and Mukumba, 2025). In SA, maize yields are prone to decline, and in the 2023/24 season, average yields were 4.87 t ha^{-1}, a 23% decline from the previous season, which was 6.35 t ha^{-1} (SAGL,2024).

Nevertheless, its importance in SA allows it to be an attractive crop for growers. In the country, it is produced by commercial, subsistence and smallholder farmers (Adisa et al., 2019). Additionally, emerging farmers also contribute by producing maize for household consumption (Chakane, 2024).

Maize production among emerging farmers is characterised by low yields, particularly due to land degradation, soil fertility declines, poor soil management and soil contamination (Ono-Raphel et al., 2025). In these

Quick Response Code	Access this article online	
	Website: www.jwbm.com.my	**DOI:** 10.26480/jwbm.01.2026.50.53

soils N and P balance is a critical determinant for successful grain production. Their synergistic interaction drives significant improvements in crop yield, nutrient uptake, and overall soil nutrient balance (Mussarat et al., 2021). Imbalances in nutrients lead to a reduction in biomass and yield as the accumulation of biomass in crops reflects their ability to use resources and the environment (Yan et al., 2023). Additionally, imbalances of these nutrients have environmental consequences such as water pollution, greenhouse gas emissions, and biodiversity loss (Jwaideh et al., 2022; Alom et al., 2025). Given these economic and environmental challenges, there is a growing need to find the best optimised N and P application rates which are environmentally safe and at the same time may be economically sound. Hence, this study assessed maize biomass yield and grain responses to different N and P levels.

2. Materials and Methods

2.1 Study Site and Experimental Design

The study was conducted at the University of Venda, Vhembe district, Limpopo province. The area is characterised by a subtropical, semi-arid climate featuring high temperatures and distinct summer rainfall (November to April) patterns. The average annual rainfall ranges between 500 and 750 mm (Shikwambana et al., 2021). The soil at the location is classified as Hutton soil, the physical and chemical properties are shown in Table 1 below (SA Soil Classification, 1991). Maize (ZM 521) grew from January to June in the first growing season, while the second growing season was from December to April. Maize seeds were sown at a spacing of 0.9 m between rows and 0.25 m within rows. Subplot sizes were 5 m by 4.5 m, giving 100 plants per subplot. The fertiliser (N and P) experiment was a 2x2 factorial, laid out in a completely randomised block design with 3 replications. Nitrogen was applied at two levels: N0 = 0 kg ha^{-1}and N1= 75 kg ha^{-1}, while P was applied at P=0 kg ha^{-1} and 30 kg ha^{-1}. For N, limestone ammonium nitrate (LAN 28% N) was used, while single super phosphate (SSP 10.5% P) was used for P. N fertiliser was applied in split applications, with 50% N applied at planting and the other 50% applied equally at V7 and tasselling stages. P was band placed at planting.

Table 1: Soil chemical and physical characteristics before treatment application

Property	Value
pH (H_2O)	5.7
Sand (%)	17.9
Silt (%)	32.9
Clay (%)	50.0
N (%)	6.8
P (ppm)	16.1

2.2 Data collection

Data collection was done on 4 pre-marked maize plants, which were the four maize plants were selected in the middle of each sub-plot and plants in the outer rows were excluded.

2.3 Soil properties

Soil samples were collected at a depth of 20 cm before planting for physical and chemical analysis. Soils were collected at several spots within the experimental plots and bulked together to make a composite sample. The composite sample was used to determine selected soil physical and chemical properties.

Soil samples were prepared and analysed using the standard analytical methods (Non-Affiliates Soil Analysis Work Committee, 1990). Particle size distribution was determined by the hydrometer method (Bouyoucos, 1962). Total N was analysed through Kjeidahl method, and P was determined using the Bray 1 method (Okalebo, 2012). Soil pH and electrical conductivity were measured using a 1:1 Soil: water ratio.

2.4 Maize biomass

Maize dry yield was collected in the subplots through a destructive method from each treatment by sampling four plants per plot 6-8 weeks after emergence, at tasseling and at harvest. The samples were dried in a forced-air oven at 65 °C for 48 hours.

2.5 Maize grain yield

Maize grain was determined at maturity by collecting maize cobs from 4 plants in the middle row in each plot. The grain was shelled and weighed, then its moisture content was determined.

2.6 Data Analysis

Data were subjected to the analysis of variance (ANOVA) using SPSS, 2006 (Version 15.0, SPSS, Chicago, IL) to assess treatment effects. Treatment means were separated according to Duncan's multiple range procedure. Differences were calculated at the 5% level. A probability level of 5% was considered significant for all tests.

3. Results and Discussion

3.1 Biomass response to treatment application

Maize biomass accumulation is influenced by several environmental and soil factors, part of which N, P and potassium (K) are the leading nutrients playing an essential role in biomass accumulation (Ma et al., 2025). In this study, maize biomass at the V7 vegetative growth stage and at the harvest stage was significantly higher in the second growing season (Figure 1: A-C). This is particularly due to the second growing season being largely in the high rainfall months. Water is the most important limiting factor for maize production (Ge et al., 2012). When soil moisture is insufficient, maize experiences drought stress (Li et al., 2024). Additionally, water influences the vitality of crop roots, photosynthesis, respiration, and the synthesis and decomposition of organic matter, ultimately affecting crop growth and yield (Yi et al., 2013). Overall, the combined N and P application showed higher biomass compared to the other treatments. This is except for the tasselling stage, where the control treatment had greater biomass in the second season compared to the rest of the treatments. Along with the second season biomass at harvest on the P-only treatment.

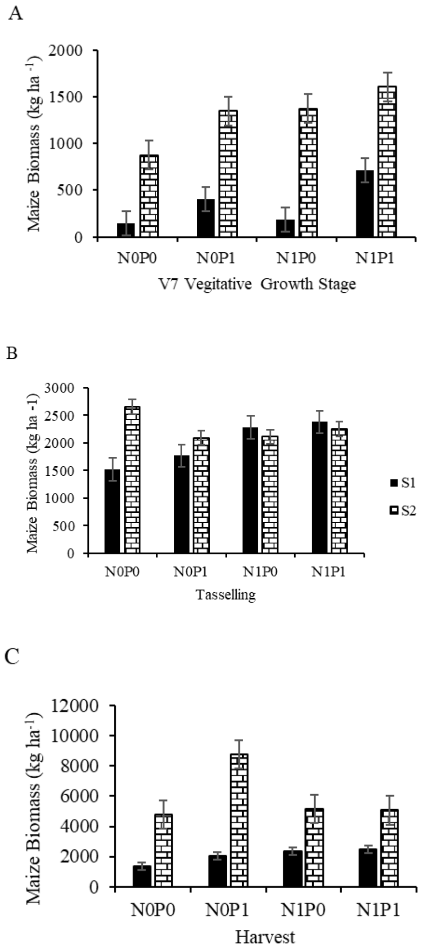

Figure 1: Effect of inorganic N and P rates on maize biomass in different growth stages. Overlapping error bars (standard error) show no significant difference at p<0.05. A= Maize biomass at 6-8weeks after planting, B=Tasselling stage, C=Harvesting stage. S1= first growing season, S2=Secon growing season

N nitrogen plays a vital role in controlling meristematic cell activity, which is essential for plant growth and development. It is a key component of proteins and nucleic acids, directly affecting cell division by increasing division rates within meristems and boosting overall plant growth (Sindesi et al., 2025b). While P, on the other hand, impacts crop yields, dry matter accumulation through stimulation of root development, which

Cite the Article: Makhaga, N.S, Sindesi O.A, Odhiambo J.J.O (2026). Maize Biomass And Yield Responses To Nitrogen (N) And Phosphorus (P) Application. *Journal of Wastes and Biomass Management, (JWBM)* , 8, (1): 50-53.

facilitates improved water and nutrient uptake (Mashece et al., 2025). The combined application of these nutrients allowed maize to increase its soil nutrient resource accumulation while also encouraging greater cell division. As standalone treatments, N and P were generally unable to meet the optimal growth potential of the maize. P deficiencies reduce crop response to applied N by interfering with photosynthetic activity and energy transfer, resulting in reduced growth and yield (Tofa et al., 2022). Additionally, in the N-only treatment, N played a critical role in photosynthesis, as N is the main component of chlorophyll and protein in the plant cells (Fathi, 2022). Nevertheless, due to P deficiencies, the obtained energy through photosynthesis was not effectively transferred to be able to convert it into biomass. This is linked to the function of P as an energy storage and transferer (Odoom and Ofosu, 2024).

3.2 Effect of Treatment Application on Maize Grain Yield Response

Maize grain yields are predominantly affected by abiotic factors such as soil and environmental factors (Kim and Lee, 2023; Iljkić et al., 2025). Among these, soil moisture and nutrients are the most important resources for grain yields (Xing et al., 2025). In this study, grain yields in the second growing season were significantly higher than those of the first growing season. This is highly linked to the second growing season (December to April), being fully in the rainy months (November to April) of the study location. According to a study, soil moisture deficits lead to reduced grain yields (Zhang et al., 2025b). During grain filling, water stress limits the grain sink potential by reducing both the rate and duration of grain filling (Yang et al., 2001; Zhang et al., 2025b). During this stage, water facilitates nutrient transportation, maintains optimal photosynthesis, and creates a hydrated environment for starch deposition (Gao et al., 2025). Additionally, in both growing seasons, grain yields were improved ($p<0.05$) by the combined application of N and P nutrients (Figure 2). N and P are two of the most essential crop macronutrients required for optimal maize grains (Bélanger et al., 2012). Proper fertilisation has been noted to increase fertiliser efficiency and contribute to improved crop growth and yields (Syafruddin et al., 2021). An appropriate N application increases the active grain-filling period and maximum grain-filling rate (Yue et al., 2022). An increased or extended grain fill period directly increases grain yields by allowing more time for photosynthesis and nutrient accumulation, leading to larger, heavier kernels (Zhang et al., 2025c). The results in Figure 2 also show that there were slightly higher ($p>0.05$) grain yields on the N-only treatment than on the P-only treatment in both growing seasons. This may be attributed to N being the primary limiting nutrient in grain production. Nitrogen application also generally led to earlier maize vegetative growth (Alem et al., 2018), as seen in Figure 1, where slight ($p>0.05$) biomass differences exist between the N-only and P-only treatments. Nevertheless, there was no significant difference between the N-only and P-only treatments, while the control had significantly lower grain yields, and N-only and combined application showed no significant difference in the second growing season.

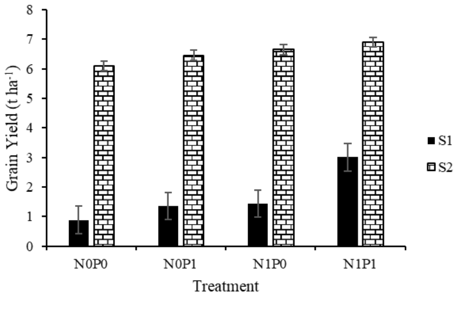

Figure 2: Maize grain yield responses to N and P application. Overlapping error bars (standard error) show no significant difference at $p<0.05$. S1= first growing season, S2=Secon growing season

4. Conclusions

This study demonstrates the importance of N and P balanced fertilisation on maize biomass and yield. It also demonstrates that soil fertility management through the strategic application of inorganic fertilisers is important for improving maize productivity. The results of the study further indicate that N is the primary limiting nutrient compared to P. Nevertheless, their combined application significantly enhances both biomass accumulation and grain yield compared to standalone treatments or the non-fertilised control. The study further underscores the climate dependency of maize. The findings show that maize performance was heavily influenced by seasonal rainfall, with the second growing season yielding significantly higher results due to better alignment with the region's high rainfall months. For resource efficiency among smallholder resource-poor farmers, implementing a balanced N and P fertiliser program overcomes low yields, which are predominantly associated with nutrient-poor soils and land degradation. Adopting these nutrient management strategies can help stabilise maize production, which remains a critical staple for food security and livestock feed in rural provinces of South Africa. Given the differences in maize yields observed in this study, future studies should investigate a wider range of N and P applications across both irrigated and rainfed maize production systems.

Funding Statement

This work was supported by UNIVEN.

Author contributions statement

Makhaga, N.S: Conceptualisation, data collection, writing of original draft. Odhiambo J.J.O: Conceptualisation, Supervision. Sindesi OA: Writing of original draft, editing of first draft.

Competing interests' policy

The authors declare no known competing interests.

Clinical trial number

Not applicable

Ethics

Not applicable

Consent to Participate

Not applicable

Consent to Publish

All authors have read the manuscript and have consented to its publication in the Discover Soil journal.

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