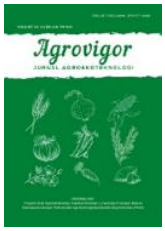
Open Access & Available Online

Agrovigor: Jurnal Agroekoteknologi

ISSN: 1979-5777 (*Print*), 2477-0353 (*Online*)

Journal homepage: https://journal.trunojoyo.ac.id/agrovigor



Article

Combination of Single and Compound Fertilizers on Nutrient Availability and Maize Response in Inceptisols Karanganyar

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ARTICLE INFO

Article history
Received: August 2026
Accepted: September 2026
Published: September 2026

Keywords
Inceptisols;
Maize;
Granular fertilizer inceptisols;
Maize;
NP granular fertilizer;
Nutrient uptake;
Soil nutrient availability;

DOI:
https://doi.org/10.21107/agrovigor.v19i2.35678

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ABSTRACT

Maize (*Zea mays* L.) is an important food and feed crop in Indonesia, but production remains insufficient to meet rising demand. Inceptisols have good potential for maize cultivation; however, their low fertility and limited nitrogen (N) and phosphorus (P) availability restrict crop growth and yield. Although single and compound fertilizers are widely used, information on effective fertilizer combinations for improving nutrient availability and maize productivity in Inceptisols is still limited. This study evaluated combinations of single N, P, K fertilizers and NP granular fertilizer to improve soil fertility, nutrient uptake, chlorophyll content, and maize yield. A randomized complete block design with nine fertilizer treatments and three replications was applied. Treatments included an unfertilized control, recommended N, P, K, 100 kg ha^{-1} NP granular fertilizer, and combinations of ¼–1 recommended N, P, K rates with 25–100 kg ha^{-1} NP granular fertilizer. Soil nutrient availability, nutrient uptake, chlorophyll content, and yield components were analyzed using analysis of variance, Duncan's multiple range test (5%), and correlation analysis. The combination of ¾ recommended N, P, K fertilizer with 75 kg ha^{-1} NP granular fertilizer produced comparable performance to the full recommended dose in enhancing nutrient availability, uptake, chlorophyll content, and yield, making it a highly efficient fertilization strategy for Inceptisols. The combination of ¾ recommended N, P, K fertilizer with 75 kg ha^{-1} NP granular fertilizer produced the best overall performance, enhancing nutrient uptake, chlorophyll content, and maize yield, making it an effective fertilization strategy for Inceptisols.

INTRODUCTION

Maize is a crucial commodity in Indonesia because it supports food security through food diversification, can also be used as animal feed, and as a raw material for other processed industries. The Ministry of Agriculture's Data and Information Center Pusdatin Kementan (2021) reported that national maize demand increased by an average of 473,000 tons between 2015 and 2019, but this contrasted with domestic productivity. This situation led Indonesia to import approximately 1,63 million tons of maize during that period (Yofa et al., 2021). Therefore, in early 2025, the government sought to increase national maize production through a maize self-sufficiency program. This program aims to increase maize production, expand planting areas, and enhance the importance of maize for the national economy (Ahmadi et al., 2025).

Inceptisols have significant potential to support national maize self-sufficiency. Considering the distribution of Inceptisols, which cover approximately 70,5 million hectares, spread across Sumatra, Java, Kalimantan, and Papua (Purwani & Nurjaya, 2021). Inceptisols are classified as marginal due to their slightly acidic pH ranging from 4.6 to 6.5 and low organic matter content (Putra et al., 2021). This soil also suffers from relatively low levels of essential macronutrients such as nitrogen, phosphorus, and potassium (Yuniarti et al., 2022). However, proper fertilization and soil management can overcome nutrient deficiencies in Inceptisols.

Nitrogen and phosphorus contribute significantly to increasing maize yields (Supandji & Saptorini, 2023). Nitrogen is essential during early growth, particularly for leaf formation, photosynthesis, and cell formation, which influences maize quality and yield (Arief & Nursagadji, 2022). However, nitrogen is easily denitrified, volatilized, and fixed by minerals (Yuliani et al., 2023). Phosphorus is widely used in early root formation and during the generative phase to aid flowering, as well as in the formation of enzymes and ATP in energy transfer processes, thus influencing maize production (Jansen et al., 2024). However, in acidic soils such as inceptisols, P readily undergoes Al and Fe fixation, making it difficult for plants to dissolve (Habi et al., 2021).

In plant fertilization practices, urea, SP-36, and KCl are still widely used as sources of nitrogen, phosphorus, and potassium (Wadi et al., 2024). However, farmers often neglect the type and timing of single fertilizers, resulting in suboptimal nutrient management. Furthermore, the limited availability of subsidized fertilizers such as urea and SP-36, as well as the high price of non-subsidized fertilizers, hinders the implementation of recommended fertilizer applications (Zulaiha et al., 2021). These conditions can hinder optimal fulfillment of plant nutrient needs (Kurniasih et al., 2023).

On the other hand, the use of compound fertilizers has the advantage of providing multiple nutrients in a single product, with practical application and homogeneous nutrient distribution (Mulyani et al., 2024). However, the nutrient composition of compound fertilizers does not always match specific plant needs or soil conditions. Therefore, a combination of single and compound fertilizers can be a strategy to increase fertilizer efficiency according to soil and plant needs without reducing productivity.

Based on these conditions, efforts are needed to reduce some of the urea and SP-36 fertilizer dosages by replacing them with compound fertilizers. The use of compound fertilizers containing nitrogen and phosphorus has the potential to partially replace urea and SP-36 dosages. The use of granular NP fertilizer with single N, P, and K fertilizers is expected to reduce the amount of single fertilizers while meeting the nutrient needs of maize crops in Inceptisols. However, studies on the combination of granular NP fertilizers and single N, P, and K fertilizers in increasing soil nutrient availability, nutrient uptake, chlorophyll, and maize yield in Inceptisols in Karanganyar, Central Java are still limited. This study aims to obtain a combination of granular NP fertilizers and single N, P, and K fertilizers that are effective in increasing nutrient availability, N and P uptake, chlorophyll content, and maize yield in Inceptisols. This study hypothesizes that partial substitution of single N and P fertilizers with granular NP fertilizers can maintain or increase soil nutrient availability, nutrient uptake, and maize yield even though the single fertilizer dose is reduced.

MATERIALS AND METHODS

The research was conducted in Jatikuwung Village, Gondangrejo District, Karanganyar Regency, Central Java, with Inceptisol soil type. Soil and plant analyses where carried out at the Soil Physics and Conservation Laboratory

and Soil Chemistry and Fertility Laboratory, Faculty of Agriculture, Sebelas Maret University (UNS). The research was conducted from Desember 2023 to May 2024.

This study used various laboratory and field tools, including hoes, trowels, 0,5 mm soil sieves, analytical scales, ovens, UV-Vis spectrophotometers, flame photometers, and pH meters. The materials used consisted of BISI-2 hybrid maize (*Zea mays* L.) seeds, Urea fertilizer, SP-26 fertilizer, KCl fertilizer, granular NP fertilizer, air-dried soil samples that had been sieved using a 0,5 mm sieve, fresh leaves taken at the maximum vegetative phase (56 DAP), maize ear, and oven-dried leaf samples. The experiment was arranged using a single-factor Randomized Complete Block Design (RCBD) with nine treatments and three replications. Each treatment was applied to a 4 × 5 m experimental plot with a spacing of 75 × 25 cm and two seeds in each planting hole, so there were 106 planting holes per plot. The recommended fertilizer dosage (1 N, P, K) consists of 350 kg ha^{-1} Urea, 200 kg ha^{-1} SP-26, and 75 kg ha^{-1} KCl. Urea fertilizer was applied in stages, with one-third of the dose at 0, 14, and 28 days after planting (DAP), while SP-26 and KCl fertilizers were applied entirely at planting time (0 DAP), and granular NP fertilizer was applied at 14 DAP. The combination were selected in accordance with the Ministry of Agriculture Regulation No. 13 of 2022. Details of the treatments used in the study are presentedas follow.

A = control treatment
B = 1 N, P, K
C = 100 kg ha^{-1} NP granular
D = 1/2 N, P, K + 100 kg ha^{-1} NP granular
E = 3/4 N, P, K + 100 kg ha^{-1} NP granular
F = 1 N, P, K + 100 kg ha^{-1} NP granular
G = 3/4 N, PK, + 25 kg ha^{-1} NP granular
H = 3/4 N, P, K + 50 kg ha^{-1} NP granular
I = 3/4 N, P, K + 75 kg ha^{-1} NP granular

Soil sampling was conducted twice: before planting and during the maximum vegetative phase (56 days after planting). Samples were taken at five points in the rhizosphere at a depth of 15–20 cm in each experimental plot. Plant tissue sampling was also conducted during the maximum vegetative phase (56 days after planting) by cutting the fourth or fifth leaf from the fully opened shoot. One leaf was taken from each observation point, resulting in five leaf samples per plot. Parameters observed included soil chemical properties, plant tissue analysis, and yield components. Soil analysis was conducted on initial soil samples and soil samples during the vegetative phase to determine pH, total nitrogen, available phosphorus, available potassium, and organic carbon. Plant tissue analysis included nitrogen uptake, phosphorus uptake, and total chlorophyll content, while yield observations included ear length, ear diameter, and 1,000-seed weight. All data obtained were analyzed using analysis of variance (ANOVA) at a 95% confidence level. If the analysis results show a significant difference ($p < 0,05$ or $p < 0,01$), then the Duncan's Multiple Range Test (DMRT) is continued. Additionally, a correlation analysis is conducted to evaluate the relationship between soil chemical properties, nutrient uptake, chlorophyll content, and maize yield.

RESULTS AND DISCUSSION

Initial Soil Characteristics

Based on initial soil characteristics, it is known that Inceptisol soil has low fertility, indicated by a total N content of 0,14%, available P content of 3 ppm, and organic Carbon content of 0,65%. The low P availability is also influenced by the slightly acidic pH of H_2O. According to Firnia (2022), a decrease in soil pH can increase the solubility of Fe and Al, which will bind P, making it easier to bind and decreasing its availability. Conversely, the available K content of 0,80 me/100 g is considered high and therefore not a major limiting factor. The soil has a sandy loam texture with a sand percentage of 83%, which is more dominant than the percentage of silt and clay fractions. This is due to the land's history as a former building site and the presence of landfilling and mixing of materials. Although the cation exchange capacity of 22,89 me/100 g is considered moderate, this initial soil fertility is still limited

by the low content of nitrogen, phosphorus, and organic carbon. This condition indicates the need for proper fertilization to increase nutrient availability for soil and plants.

Table 1. Soil Characteristics of Inceptisol

Properties	Value	Units	Harkat*
pH H_2O	6,40	-	A bit sour
N Total	0,14	%	Low
P Available	3,0	ppm	Very low
K Available	0,80	me/100g	Height
Organic Carbon	0,65	%	Very low
CEC	22,89	me/100g	Medium
Soil Texture	Silt 6,24 *Clay* 10,33 Sand 83,43	%	Sandy Clay Loam

Notes: *Certification based on the Testing Center Soil and Fertilizer Instruments 2023

NP Granular Fertilizer Test Results

Granular NP fertilizer is a compound fertilizer containing both nitrogen (N) and phosphorus (P). Testing was conducted to prove that the fertilizer meets the quality standards set by the Ministry of Agriculture based on Regulation No. 209/Kpts/SR.320/3/2018. Granular NP fertilizer contains 15,20% N and 15,11% P_2O_5, indicating that its main nutrient content complies with the Indonesian National Standard (SNI). However, the water content of granular NP fertilizer is 2,66% higher than the standard of a maximum of 1%. The results of heavy metal analysis indicate that the content of As, Hg, Cd, Cr, Pb, and Ni is within safe limits according to SNI. The low metal content in the fertilizer composition indicates that the raw materials used do not have the potential to cause environmental pollution or heavy metal accumulation in plants and crops. Overall, granular NP fertilizer meets the requirements for good product quality testing standards and can proceed to other testing stages. Thus, granular NP compound fertilizer has the potential to be an effective source of nitrogen and phosphorus nutrients to enhance plant growth and development.

Table 2. Characteristics of NP Granular Fertilizer

Parameter	Units	Value
N levels	%	15,20
P_2O_5 levels	%	15,11
Water content	%	2,66
Heavy metal		
As level	ppm	<0,003
Hg levels	ppm	<0,002
Cd levels	ppm	<0,07
Pb levels	ppm	<0,04
Cr levels	ppm	48,26
Ni level	ppm	46,47

Soil Nutrient Availability

The application of a combination of single N, P, K fertilizers and compound fertilizer NP granular had a significant effect on total soil N ($p<0,05$). The highest value was obtained in the treatment of ¾ N, P, K + 75 kg ha^{-1} NP granular (I) at 0,25% but was not significantly different from the full dose treatment of 1 N, P, K + 100 kg ha^{-1} NP

granular (F) at 0,24% and ¾ doses of N, P, K + 25 and 50 kg ha^{-1} which were each 0,23% (Table 3). Treatment I increased the total soil N content by 108,33% compared to the control treatment and 66,67% compared to the standard N, P, K treatment (B), so that the soil N status increased to the medium category. The increase in total N was related to the addition of nitrogen from urea fertilizer and NP granular. In treatment F, a higher N dose can trigger N loss through leaching and denitrification-volatilization, so the amount of the dose given is not always followed by an increase in the total N content of the soil. This can be seen in treatment I, which has an N dose input that has reached the equilibrium limit, so the total N content is equivalent to treatment F. According to Ayu et al. (2023), applying N fertilizer in high doses can increase the total N content of the soil, but is also influenced by the fertilizer form, application time, plant uptake, and N loss in the soil. Treatment between a single fertilizer N, P, K (B) and compound fertilizer NP granular (C). The total N content in treatment C is higher than treatment B, even though the dose given is higher than treatment C. Table 3 generally indicates that compared to single fertilizer N, P, K, the combination treatment of 75% single fertilizer with NP granular can maintain the total N content even though the single fertilizer dose is reduced by 25%. This proves that granular NP fertilizer can increase fertilization efficiency and has a positive effect on soil nutrition. The granular form of compound NP fertilizer is related to the release of nutrients into the soil. Compared to powdered or crystal fertilizers, which have smaller particle sizes and therefore dissolve easily, granular fertilizers have larger particles, allowing for a gradual dissolution process. This allows for controlled nutrient release by adjusting soil moisture (Sigtryggsson et al., 2022). After application, granular NP fertilizer transforms nitrogen into mineral forms, primarily NH_4^- and NO_3^-, which can be utilized by plants. Therefore, the granular form is able to release nutrients gradually and maintain the availability of N and P around the roots to support nutrient uptake by plants.

The combination of single compound granular fertilizers significantly affected soil available P ($p<0,05$). The highest value was obtained in the treatment of ¾ N, P, K + 75 kg ha^{-1} NP granular (I) of 38,50 ppm. The available P value in standard N, P, K (B) of 9,07 ppm and 100 kg ha^{-1} NP granular (C) of 11,46 ppm was significantly different from the combination treatment (D-I) which had a very high available P content. Treatment I was able to increase available P by up to 324,48% compared to the standard N, P, K treatment (B) and increased by 1,196% compared to the control treatment (A). This increase was in line with the addition of P fertilizer from NP granular and SP-26 fertilizers, so that the P concentration in the soil solution, especially in the combination treatment, increased. P availability was also related to soil pH after treatment which ranged from 7.5-7.7 (neutral - slightly alkaline). Treatment G, with a pH of around 7.5, demonstrated a low available P value due to fixation by Ca and Mg cations. According to Firnia (2022), alkaline conditions deprotonate to HPO_4^{2-}, which can react with Ca^{2+} and Mg^{2+} to form poorly soluble Ca-P or Mg-P. However, in this study, treatment I had a higher available P value than treatment F, even though both had the same pH. These findings confirm that treatment I achieved soil nutrient balance, while treatment F experienced a decrease in soil nutrient balance. Soil nutrient balance will trigger optimal absorption of other nutrients, resulting in better plant growth. The granular form of NP fertilizer also affects the pattern of P release in the soil. Phosphate that has dissolved in the soil solution then moves to the total yield component root zone through a diffusion process (Edy & Ibrahim, 2022). The increase in available P also supports chlorophyll formation, as indicated by the positive correlation between available P and total chlorophyll content of r=0,754**.

Table 3 shows that the lowest available K was in the control treatment (A) which was 0,12 me/100g and the highest value was in the treatment ¾ N, P, K + 75 kg ha^{-1} NP granular (I) which was 0,16 me/100g. The treatment that had the highest available K, namely treatment I, showed no significant difference with the treatments 1 N, P, K + 100 kg ha^{-1} NP granular (F), ¾ N, P, K + 25 kg ha^{-1} NP granular (G), and ¾ N, P, K + 50 kg ha^{-1} NP granular (H) which each had a value of 0,15 me/100g. Although the KCl dose in treatment F was higher than treatment I, the available K value was relatively the same, so that available K was not only determined by the amount of KCl given. The available K levels in all treatments, from A to I, were all relatively low compared to the initial high available K levels of 0,80 me/100g. According to Fitria et al. (2021), the decrease in available K indicates that as plant growth progresses, soil K availability tends to decrease due to plant uptake, particularly during the vegetative phase, to support stem development and the formation of carbohydrates and starch, which play a crucial role in seed filling. The soil pH after treatment, which ranged from 7.5 to 7.7, indicated a low concentration of H+ ions. According to Aibekob et al.

(2024), a high pH does not necessarily guarantee high available K levels because the soil's ability to retain K^+ is largely determined by its CEC, mineral type, organic matter, and leaching processes. The soil in this study was predominantly composed of sand at 83,43%, which facilitated K migration and leaching from the root zone. This resulted in lower available K values compared to the initial high available K levels, even though KCl fertilizer had been applied.

Table 3. Effect of Combination of Single Fertilizer and Compound Granular on Nutrient Availability

Code	pH	N Total (%)	P Available (ppm)	K Available (me/100 g)	Organic Carbon (%)
A	7,6^{a}	0,12^{a}	2,97^{a}	0,12^{a}	0,65^{a}
B	7,7^{a}	0,15^{b}	9,07^{a}	0,14^{ab}	1,46^{b}
C	7,7^{a}	0,19^{c}	11,46^{a}	0,13^{ab}	1,60^{bc}
D	7,6^{a}	0,21^{cd}	22,55^{b}	0,13^{ab}	1,68^{cd}
E	7,6^{a}	0,22^{de}	27,46^{bc}	0,13^{ab}	1.79^{de}
F	7,7^{a}	0,24^{e}	31,51^{cd}	0,15^{bc}	1,97^{ef}
G	7,5^{a}	0,23^{de}	20,62^{b}	0,15^{bc}	1,90^{ef}
H	7,6^{a}	0,23^{de}	20,41^{b}	0,15^{bc}	1,91^{ef}
I	7,7^{a}	0,25^{e}	38,50^{d}	0,16^{c}	2,00^{f}

Notes: Values followed by the same letter show no real difference, based on the results of further tests using DMRT. The code A = control; B = 1 N, P, K; C = 100 kg ha^{-1} NP granular; D = 1/2 N, P, K + 100 kg ha^{-1} NP granular; E = 3/4 N, P, K + 100 kg ha^{-1} NP granular; F = 1 N, P, K + 100 kg ha-^{1} NP granular; G = 3/4 N, PK, + 25 kg ha^{-1} NP granular; H = 3/4 N, P, K + 50 kg ha^{-1} NP granular; I = 3/4 N, P, K + 75 kg ha^{-1} NP granular.

The highest organic carbon was found in the ¾ N, P, K + 75 kg ha^{-1} NP granular (I) treatment, which was 2,00% but was not significantly different from treatments F, G, and H, which produced 1,97%, 1,90%, and 1,91%, respectively (Table 3). Treatment I was able to increase organic carbon by 207,69% compared to the control treatment (A) and 36,99% compared to the standard N, P, K treatment (B), although the value was still considered low. The increase in organic carbon is thought to occur indirectly through plant responses to fertilization. According to Machfud et al. (2023), nutrient availability can increase root growth and activity that produce exudates as a carbon source for rhizosphere microorganisms. Treatment I produced the highest organic carbon although not significantly different from F. This is because both treatments have a relatively high nutrient supply, thus being able to create conditions that support root growth and soil microorganism activity. However, treatment I compared to a lower single fertilizer dose was able to produce organic carbon equivalent to treatment F. This indicates a nutrient balance compared to just increasing the fertilizer dose.

Treatment ¾ N, P, K + 75 kg ha^{-1} NP granular (I) was 5,86 g/plant (Table 4). Treatment I was not significantly different from the full dose of 1 N, P, K + 100 kg ha^{-1} NP granular (F) which had an N uptake value of 5,31 g/plant, this indicates that high fertilizer doses do not always increase nutrient uptake in plants. Treatment I was able to increase N uptake by 37,88% against standard N, P, K (B) and 589,41% against the control (A). N uptake in the treatment ¾ N, P, K + 25 and 50 kg ha^{-1} NP granular (G and H) was 2,69 and 4,32 g/plant, respectively. Although statistically different, both were not significantly different based on the DMRT test. Differences in N uptake values are related to dry plant weight because N uptake is calculated by multiplying tissue N content by plant dry weight. According to Afrianti et al. (2025), increasing plant biomass and soil N availability can increase N accumulation in plant tissues. This is supported by a positive correlation between total soil N and N uptake of r=0,463*, indicating that increased soil N reserves are associated with increased plant N uptake (Sofyan et al., 2023).

The treatment with the highest P uptake value was ¾ N, P, K + 75 kg ha^{-1} granular NP (I) at 0,54 g/plant (Table 4). P uptake in the control treatment (A) was 0,26 g/plant which was not significantly different from the combination treatment of ¾ N, P, K + 100 kg ha^{-1} NP granular (E) of 0,27 g/plant and ¾ N, P, K + 25 kg ha^{-1} NP granular (G) of 0,30

g/plant. These results indicate that the addition of phosphorus-containing fertilizers such as SP-26 in treatments E and G has not been followed by a significant increase in P accumulation by plants compared to the control. In line with the statement of Arafat et al. (2021), that the increase in P uptake in maize crops is in line with the increase in plant dry weight.

Plant Nutrient Uptake

Treatment I was significantly different from the control treatment (A) with an increase in P uptake of 107,69% each. This indicates that the combination of single N, P, K fertilizers and NP granular is able to increase P availability in the soil, thereby increasing P available in the soil solution and increasing P uptake. In accordance with the statement of Yuniarti et al. (2022), plants absorb phosphate through root interception and short-range diffusion (<0,02 cm), so that P availability around the root zone determines the extent of P uptake by plants. In line with this, the results of Pearson correlation analysis showed that P uptake was significantly positively correlated with available P (r = 0,536**). This indicates that increasing P availability in the soil also increases P uptake by plants (Lestari et al., 2022).

Table 4. Effect of Combination of Single Fertilizer and Compound Granular on Nutrient Uptake

Code	N Uptake (g/plant)	P Uptake (g/plant)
A	84,64^{a}	25,54^{a}
B	425,39^{bc}	42,46^{abc}
C	368,59^{bc}	39,84^{abc}
D	463,92^{bc}	47,68^{bc}
E	331,58^{abc}	26,91^{a}
F	530,68^{bc}	51,52^{c}
G	269,21^{ab}	29,72^{ab}
H	432,27^{bc}	46,60^{bc}
I	586,28^{c}	53,93^{c}

Notes: Values followed by the same letter show no real difference, based on the results of further tests using DMRT. The code A = control; B = 1 N, P, K; C = 100 kg ha^{-1} NP granular; D = 1/2 N, P, K + 100 kg ha^{-1} NP granular; E = 3/4 N, P, K + 100 kg ha^{-1} NP granular; F = 1 N, P, K + 100 kg ha-$^{-1}$ NP granular; G = 3/4 N, PK, + 25 kg ha^{-1} NP granular; H = 3/4 N, P, K + 50 kg ha^{-1} NP granular; I = 3/4 N, P, K + 75 kg ha^{-1} NP granular.

Total Chlorophyll Content

Chlorophyll, the green pigment in chloroplasts, is a key factor in photosynthesis (Istri & Dharmadewi, 2021). Chlorophyll captures sunlight during photosynthesis to convert it into carbohydrates and produce ATP and NADPH (Waruwu et al., 2024). Therefore, chlorophyll content influences the photosynthesis process. Total chlorophyll content is calculated based on the sum of chlorophyll a and chlorophyll b in leaf tissue.

Table 5 shows that the ¾ N, P, K + 75 kg ha^{-1} NP granular (I) treatment had the highest chlorophyll content at 2,62 mg/g leaf. Chlorophyll content in treatment I increased by 94,07% compared to the control treatment (1,35 mg/g leaf) and by 45,56% compared to the standard N, P, and K (B). At the standard N, P, K dose (B), the chlorophyll content was 1,80 mg/g leaf, which was significantly different from the combination treatment of ½ N, P, K + 100 kg ha^{-1} NP granular (D) of 2,27 mg/g leaf. This indicates that the provision of N and P nutrients derived from single NPK fertilizers and NP granular can increase leaf chlorophyll content. Although treatment I was not significantly different from treatment F, treatment I statistically showed superior chlorophyll content. This is related to the nutrient balance that supports more optimal N absorption (Table 4). In addition, the use of 100 kg ha^{-1} NP granular (C) compared to standard N, P, K (B) provided a better response.

The application of compound fertilizer NP granular allows the provision of N and P elements simultaneously so that nutrient distribution is more homogeneous and supports root activity in absorbing the elements needed by plants. This condition supports chlorophyll formation, because N and P are important in the process of photosynthesis. In accordance with the statement of Salim et al. (2025), the application of nitrogen-containing fertilizers will increase chlorophyll content, while phosphorus is also important in root development to help absorb nutrients needed by plants for chlorophyll synthesis. Therefore, increasing available N will help increase chlorophyll formation so that leaf color becomes greener and photosynthetic capacity will increase (Hulu et al., 2026). In line with the results of the correlation test which showed a significant positive correlation between total chlorophyll and N uptake (r = 0,561**). Ardiansyah et al. (2022) stated that there is a strong relationship between chlorophyll and N uptake so that chlorophyll can be used to describe the nitrogen status of plants.

Table 5. Effect of Combination of N, P, K Single and NP Granular Fertilizers on Total Chlorophyll

Code	Chlorophyll (mg/g leaves)
A	1,35^{a}
B	1,80^{b}
C	2,15^{c}
D	2,27^{cd}
E	2,35^{de}
F	2,60^{f}
G	2,48^{ef}
H	2,51^{ef}
I	2,62^{f}

Notes: Values followed by the same letter show no real difference, based on the results of further tests using DMRT. The code A = control; B = 1 N, P, K; C = 100 kg ha^{-1} NP granular; D = 1/2 N, P, K + 100 kg ha^{-1} NP granular; E = 3/4 N, P, K + 100 kg ha^{-1} NP granular; F = 1 N, P, K + 100 kg ha-^{1} NP granular; G = 3/4 N, PK, + 25 kg ha^{-1} NP granular; H = 3/4 N, P, K + 50 kg ha^{-1} NP granular; I = 3/4 N, P, K + 75 kg ha^{-1} NP granular.

Maize Yield

The combination of single N, P, K fertilizer and NP granular fertilizer significantly affected the length and diameter of maize ear ($p<0.05$). The highest ear length was obtained in the treatment of ¾ dose of N, P, K + 75 kg ha^{-1} NP granular (I) of 19.50 cm, an increase of 41,30% compared to the control of 13,80 cm and 8,94% compared to the standard N, P, K (B) of 17,90 cm. Based on Table 6, treatment I was significantly different from the control and ¾ N, P, K + 25 kg ha^{-1} NP granular (G), but not significantly different from the other treatments. However, the highest value in treatment I indicates that the combination was able to support better ear growth. According to Tobing et al. (2022), this occurs because sufficient N fertilization can increase biomass, ear length and diameter and maize grain weight because N supports the formation of chlorophyll and photosynthates which can be utilized for ear growth and grain filling.

The maize ear diameter after applying 100 kg ha^{-1} of granular NP (C) was 3,86 cm, significantly different from the standard N, P, and K (B) of 3,81 cm. Although the difference was only 1.31%, this result indicates that granular NP fertilizer provided a better response than standard N, P, and K. According to Mulyani et al. (2024), compound fertilizers contain several elements in one product with a more homogeneous and even distribution to plants. The response in ear diameter is also indicated to be related to the simultaneous availability of N and P. Nitrogen supports biomass formation and photosynthesis, while phosphorus supports energy transfer, root development, and the formation of generative organs. Research conducted by Lukman (2022) showed that fertilizers providing nitrogen and phosphorus can increase ear diameter and sweet maize yield. The correlation results show that ear length has a significant positive correlation with the 1,000-seed weight (r=0,540**), while ear diameter has a significant positive

correlation (r=0,578**). These results align with Karomah et al. (2023), who found that increases in ear length and diameter tend to be followed by increases in the 1,000-seed weight.

Table 6. Effect of Combination of Single Fertilizer and Compound Granules on Maize Yield

Code	EL (cm)	ED (cm)	Weight 1,000 Seeds (g)
A	13,80[a]	3,52[a]	215,00[a]
B	17,90[bc]	3,81[a]	247,33[b]
C	17,33[bc]	3,86[bc]	227,00[ab]
D	18,30[bc]	3,91[c]	237,33[ab]
E	18,93[bc]	4,15[de]	241,67[b]
F	19,13[bc]	4,23[de]	251,00[b]
G	16,83[b]	4,14[de]	236,00[ab]
H	17,67[bc]	4,16[de]	249,00[b]
I	19,50[c]	4,24[e]	252,33[b]

Notes: Values followed by the same letter show no real difference, based on the results of further tests using DMRT *EL = Ear Length (cm); ED = Ear Diameter (cm). The code A = control; B = 1 N, P, K; C = 100 kg ha^{-1} NP granular; D = 1/2 N, P, K + 100 kg ha^{-1} NP granular; E = 3/4 N, P, K + 100 kg ha^{-1} NP granular; F = 1 N, P, K + 100 kg ha-^{1} NP granular; G = 3/4 N, PK, + 25 kg ha^{-1} NP granular; H = 3/4 N, P, K + 50 kg ha^{-1} NP granular; I = 3/4 N, P, K + 75 kg ha^{-1} NP granular.

1,000-grain weight in the combination of ¾ N, P, K + 75 kg ha^{-1} granular NP (I) was 252,33 g, which was not significantly different from the combination of 1 N, P, K + 100 kg ha^{-1} granular NP (F) at 251 g (Table 6). 1000-grain weight in the standard N, P, and K (B) treatment (B) was 247,33 g, which was not significantly different from treatment I. This indicates that treatment I only increased 1,000-grain weight by 2.02% compared to the standard N, P, and K (B) and by 17.36% compared to the control (A). Although 1,000-grain weight between treatments I and F was not significantly different, treatment I showed higher ear length and ear diameter values than F. This condition indicates that treatment I has the potential to produce a higher number of seeds per ear. Meanwhile, treatments C, D, and G were not significantly different from the control, so that the addition of the combination dose was not enough to significantly increase 1,000-grain weight.

Based on the description of the maize variety BISI-2, it has a weight of 1,000 grains of around 310 g, so the highest value in this study only reached 81.40% of the weight character of the variety and cannot be said to have reached its maximum genetic potential. The difference in response between treatments indicates that 1,000-grain weight is not only determined by the addition of fertilizer, but also the balance of nutrients during the grain filling phase. Tobing et al. (2022) also showed that increasing the N dose can increase the yield of maize components but does not always have a significant effect on 1,000-grain weight. Although some treatments showed no significant differences with the same fluctuation pattern in 1,000-seed weight, Pearson correlation analysis results showed a positive and significant relationship to N uptake (r = 0,502**) and P uptake (r = 0,418*). This indicates that overall increases in N and P uptake tended to be followed by increases in 1,000-seed weight, but uptake of these two nutrients was not the main factor determining the differences between treatments.

CONCLUSION

The combination of single and compound granular fertilizers improved nutrient availability and maize performance in Inceptisols. The most effective treatment was 75% of the recommended N, P, and K dose plus 75 kg ha^{-1} granular NP. It increased organic C, total N, available N and P, N and P uptake, chlorophyll, and yield components. Reducing single N, P, K by 25% while adding granular NP maintained or improved nutrient-use efficiency and maize response, supporting sustainable fertilization.

ACKNOWLEDGMENTS

The author appreciates and thanks the laboratory and staff of the Soil Physics and Conservation Laboratory and the Soil Chemistry and Fertility Laboratory, FP UNS for providing permits, use of facilities and support during the research implementation process.

AUTHORS CONTRIBUTIONS

Jauhari Syamsiyah, Hery Widijanto and Ristiya Adi Wiratama contributed to the conceptualization, research design, and methodology development. Sabarina Ayuningtyas contributed to the field experiments and laboratory analyses. All authors contributed to data analysis, data interpretation, manuscript preparation, and revision of the final manuscript. All authors have read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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