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AGROECOLOGICAL MODEL EMPLOYMENT WITH INTERCROPPING BETWEEN MAIZE AND SOYBEAN

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SUMMARY

Maize (*Zea mays* L.) and soybean (*Glycine max* L.) cultivation face constraints, such as decreased soil fertility, biodiversity loss, increased pest and disease problems, and vulnerability to climate change. However, agroecology has gained recognition for its potential to address the environmental and social challenges in food production. This study aimed to investigate the agroecological aspects of cultivation through intercropping of maize and soybean in addition to organic and inorganic fertilizers to support the efforts toward better and sustainable food security. The research transpired in the District of Meureubo, West Aceh Regency, Indonesia. The study, carried out in a randomized complete block design, had two factors, i.e., cultivars (four groups of maize and soybean genotypes) and five fertilizer levels. The data recorded focused on the morphological characteristics of maize and soybean plants. The results showed the intercropping of maize cultivar Exotic + soybean cultivar Detap-1 with 25% of the recommended dose of inorganic fertilizer + 30 t/ha organic fertilizer gave the best performance. The lowest outcomes resulted in the intercropping of maize cultivar Bonanza + soybean cultivar Grobogan with 100% of the recommended dose of inorganic fertilizer.

Keywords: Maize (*Z. mays* L.), soybean (*G. max* L.), climate mitigation, food resilience, agroecological aspects, intercropping, organic fertilizer, morphological traits

Key findings: The intercropping of maize cultivar Exotic and soybean cultivar Detap-1 with 25% of the recommended dose of inorganic fertilizer + 30 t/ha organic fertilizer revealed the best performance of both crops.

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INTRODUCTION

Organic fertilizers release fewer greenhouse gases than synthetic fertilizers, thereby contributing to climate change mitigation efforts. These sustainable inputs promote biodiversity in farming systems, reduce dependence on monocultures, and enhance resilience to pests and diseases. Moreover, these organic fertilizers encourage the proliferation of beneficial microorganisms, thus improving nutrient cycling and soil health. Encouraging the use of locally sourced organic material as fertilizers strengthens the rural economy and also reduces reliance on imported chemical inputs.

One of the most challenging problems arising from climate change, food insecurity, and the depletion of agricultural resources is how to build a profitable cropping system to optimize land use and increase farmers' income (Diacono *et al.,* 2016). Extreme drought and floods significantly affect soil fertility, plant growth, pests and diseases, and eventually reduce crop yields and compromise food security (Altieri *et al.,* 2015).

In the agricultural sector, various problems cause a significant decrease in soil fertility, leading to the development of agroecology, which reintroduces ecological principles into agricultural practices. Defining agroecology can be broadly as the agro-environmental science, which has the application of ecological knowledge in managing agricultural systems. In practice, agroecology involves applying ecological concepts to field research, design, and management of agriculture and food systems (Puspitasari, 2018). Sustainable agricultural development must achieve a balance between the economic goals and social environmental considerations (Gutzler *et al.,* 2015).

Agroecology is not merely a concept, but also an agricultural philosophy and practice integrating ecological principles into agricultural systems (Silva-Galicia *et al.,* 2021). These principles include the wise use of natural resources, the enhancement of biodiversity, the improvement of soil health, and the development of agricultural systems more resilient to the impacts of climate change (Sarvade *et al.,* 2019; Silva-Galicia *et al*., 2021). Agroecology has become increasingly recognized in policy due to its potential to address environmental and social challenges in food production (Bezner *et al.,* 2021). It introduces a novel methodology by identifying optimal configurations of sustainable land use to maximize specific social objectives through ecofunctional intensification practices, which aim to reduce the yield gap relative to industrial agriculture (Padro *et al.,* 2020).

The maize's deep root system and ability to absorb nutrients from deeper soil layers help improve resource capture efficiency and also act as a barrier to soil erosion and increase the availability of nutrients for soybeans (Pratiwi, 2012). Soybeans can also increase soil nitrogen through symbiosis with rhizobia, which can positively affect maize growth and reduce dependency on synthetic fertilizers. The intercropping of maize and soybean has an advantage over planting them individually (Tasisa, 2020) (Figure 1). The soybean-maize intercropping technology introduced by IAARD (Indonesian Agency for Agricultural Research and Development) at the Maize Production Center at LKIK Tuban Regency, provides higher economic benefits than the monoculture (Elisabeth and Harsini, 2020). The intercropping of maize and soybean has a considerable effect on the production of both crops (Matusso, 2014).

Organic fertilizers are generally more environmentally friendly, minimizing carbon emissions, and mitigating the water pollution risks (Zahoor and Mustaq, 2023). The recommended fertilization doses had a significant impact on the length and weight of sweet corn cobs, and each experimental land is suitable for multiple cropping, as evidenced by the Land Equivalent Ratio value of >1 (Herlina *et al.,* 2015). The presented research aimed to examine the agroecological aspects of cultivation through intercropping of maize and soybean in addition to organic and inorganic fertilizers to support efforts toward better and sustainable food security.

Figure 1. Intercropping pattern between maize and soybean.

MATERIALS AND METHODS

The promising research commenced at the Alue Peunyareng, District of Meureubo, West Aceh Regency, Indonesia. The materials used in this study were seeds of the maize cultivars Bonanza and Exotic and seeds of the soybean cultivars Detap-1 and Grobogan, compost, fertilizers (urea, SP36, and KCL), dolomite, and others. The tools used in this study included a hoe, rake, digital scale, vernier caliper, cutting machete, pointed soil shovel, water hose, among others. The study used a randomized complete block design layout with two factors, including four groups of maize and soybean cultivars and five fertilizer levels. The details on both factors and the treatments are available in Table 1.

The treatment combinations totaled 40, with three replications, and plots totaling 60 had a plot size of 2 m × 3 m. Eight sample plants per plot comprised four maize and four soybeans. The total number of plants was 3,360, with the number of sample plants being 480. The data recorded were on various morphological characteristics of maize and soybean plants. In maize, the studied variables were plant height (cm), number of leaves (leaf), and stem diameter (cm), while in soybeans, they were plant height (cm) and number of productive branches (branches). The sampling time proceeded at 14 days after planting (DAP), 21, 28, 35, 42, and 49 DAP. All data underwent statistical analysis using the F-test, and the means with significant differences continued further comparison and separation by the Tukey's ($LSD_{0.05}$) test.

RESULTS AND DISCUSSION

Cultivar and fertilization interaction effects on maize

The intercropping of soybean-maize cultivars Exotic (maize) + Detap-1 (soybean) with a fertilization of 25% of the recommended dose of inorganic fertilizer + 30 t/ha of organic fertilizer revealed the maximum plant height (cm) in maize plants (Table 2). The intercropping between maize and soybean requires proper fertilizer management and selection of cultivars so both crops can grow optimally, including for maize plant height. The interaction between maize cultivars and fertilization doses plays an important role in

Table 1. Design of the factors and treatments used in the study.

Factor I: Maize and soybean cultivars	
Treatment code	Cultivar names
V1	Bonanza (maize) + Detap-1 (soybean)
V2	Exotic (maize) + Detap-1 (soybean)
V3	Bonanza (maize) + Grobogan (soybean)
V4	Exotic (maize) + Grobogan (soybean)
Factor II: Fertilizer levels	
Treatment code	Treatments
D1	100% recommendations: (Maize: 300 kg ha^{-1} Urea + 150 kg ha^{-1} SP36 + 50 kg ha^{-1} KCl); (Soybean: 30 kg ha^{-1} Urea + 60 kg ha^{-1} SP-36 + 30 kg ha^{-1} KCl)
D2	75% of recommendations + 10 t/ha of Organic Fertilizer
D3	50% of recommendations + 20 t/ha of Organic Fertilizer
D4	25% of recommendations + 30 t/ha of Organic Fertilizer
D5	40 t/ha Organic Fertilizer

Table 2. Maize cultivars and fertilizer levels interaction effects on the plant height at the age of 14, 21, 28, and 35 DAP.

Ages	Treatments	Fertilizer levels				
	Cultivars	D1	D2	D3	D4	D5
14 DAP	V1	19.59ab	20.92ab	19.66ab	23.23ab	22.78ab
	V2	18.38ab	16.66b	19.63ab	22.18ab	20.50ab
	V3	20.12ab	19.63ab	21.19ab	24.05a	21.95ab
	V4	18.53ab	17.76ab	18.71ab	18.48ab	21.67ab
21 DAP	V1	28.33abcd	33.68abcd	31.08abcd	40.04ab	37.63abc
	V2	24.14cd	22.28d	26.96bcd	41.63ab	34.89abcd
	V3	27.88bcd	32.1abcd	35.92abcd	42.94a	33.23abcd
	V4	24.23cd	27.04bcd	28.33abcd	31.00abcd	36.75abcd
28 DAP	V1	43.45ab	53.11ab	49.03ab	63.56ab	64.21ab
	V2	40.36ab	36.63b	45.23ab	69.97a	60.11ab
	V3	40.85ab	54.97ab	57.01ab	70.15a	54.35ab
	V4	37.23b	43.26ab	47.83ab	50.25ab	59.74ab
35 DAP	V1	63.73bc	76.20abc	84.80abc	88.34abc	95.10abc
	V2	63.42bc	57.61c	69.74abc	106.52a	89.82abc
	V3	58.77c	82.09abc	82.39abc	101.46ab	80.28abc
	V4	57.25c	65.63bc	72.08abc	79.03abc	91.13abc

Note. The same letters in each column indicate nonsignificant differences among the means by using Tukey's test; DAP = days after planting.

determining plant growth, especially in resource competition conditions with soybean. Salawati and Ende (2023) also reported that the combination of different maize and soybean cultivars has varied adaptability in the intercropping systems.

In an intercropping system, the fertilizer doses require adjustment for both crops (maize and soybeans) to get the adequate nutrients without sacrificing each other. Proper fertilization, especially of nitrogen, is essential for enhanced plant height in maize plants (Pernitiani *et al*., 2018). The intercropping system needs careful fertilization management due to nutrient competition between maize and soybean crops. In specific maize cultivars, balanced fertilization was evident with significantly increased plant height, especially if the planted soybean also contributed nitrogen through nitrogen fixation (Panunggul *et al.,* 2023).

The combined use of inorganic and organic fertilizers is one of the effective strategies for enhancing maize plant growth

(Irsyad and Kastono, 2019). The inorganic fertilizers provide quickly absorbed nutrients, while organic fertilizers improve the soil structure and provide nutrients gradually (Simanungkalit *et al.,* 2006). Inorganic fertilizers supply the essential major nutrients (nitrogen, phosphorus, and potassium) as directly absorbed by crop plants, promoting vegetative growth. Organic fertilizers, such as compost and manure, help improve soil structure, increase water and nutrient absorption capacity, and also give micronutrients unavailable in inorganic fertilizers (Mansyur *et al.,* 2021). The different types and doses of green manure augment growth and yield-related traits, such as leaf area, stem diameter, cob length, 100-grain weight, and maize production (Nasir *et al.*, 2021).

The most number of maize plant leaves (28 and 35 HST) was visible in the maize-soybean intercropping system Exotic (maize) + Detap-1 (soybean) with 25% of the recommended dose of inorganic fertilizer + 30 t/ha of organic fertilizer (Table 3). This outcome was an expectation, as each crop variety requires an optimal fertilization dose in the intercropping system. In intercropping systems, balanced fertilization is essential for nutrient availability in the soil to boost growth. Maruapey (2012) mentioned that different maize cultivars have varied growth potential, including the number of leaves produced. The hybrid maize cultivars tend to have more leaves than native cultivars due to faster photosynthesis and vegetative growth (Dewi *et al.,* 2023). In an intercropping system, it is vital to select the appropriate maize variety to optimize its interaction with soybean, ensuring that both crops can obtain sufficient nutrient resources for better growth (Sundari and Mutmaidah, 2019).

The right dosage of fertilizer plays an influential role in supporting leaf growth, especially in the intercropping system with competition between crop plants. In the maize-soybean intercropping, maize is the major crop requiring sufficient nitrogen for vegetative growth, including leaf formation. Balanced fertilization includes nitrogen, phosphorus, potassium, and organic fertilizers, greatly affecting the number of leaves in crop plants (Pangestu, 2022). Maize cultivars with the highest production potential will respond to higher fertilization doses with an increase in the leaf number. Pangaribuan *et al.* (2018) stated that certain maize cultivars with an increased number of leaves in response to fertilization can support photosynthetic ability, and, subsequently, enhance maize productivity in the intercropping.

Herlina and Widodo (2019) reported that balanced fertilization involving a combination of nitrogen, phosphorus, potassium, and organic fertilizers in appropriate amounts is crucial to the maintenance of the growth and productivity of maize plants. The use of an optimal dose of fertilizers, according to the specific needs of the crop variety, can raise plant height, leaf count, stem diameter, and yield in maize (Amanda *et al.,* 2023). The management of these nutrients requires consideration, as both nutrient overdoses and deficiencies can result in lowered plant height and other growth-related traits.

The highest stem diameter (cm) of maize plants (28 and 35 HST) (Table 4) was noticeable in the intercropping system of maize (Exotic) and soybean (Detap-1) cultivars with 25% of the recommended dose of inorganic fertilizer + 30 t/ha of organic fertilizer (Table 4). The interaction between maize-soybean cultivars and the fertilization with N, P, and K nutrients and organic fertilizers greatly affects the maize stalks' diameter in the intercropping with soybean. Balanced fertilization is crucial in intercropping systems, as maize and soybean compete for nutrients (Du *et al.,* 2018). Better fertilization management will increase the strength of the maize stalks and support the overall productivity of the intercropping system (Belel *et al*., 2014). Maize cultivars with higher competitiveness in nutrient acquisition tend to have larger stem diameters, especially when supported with adequate fertilization (Subedi and Ma, 2009).

Table 3. Maize cultivars and fertilizer levels interaction effects on the number of leaves at the age of 28 and 35 DAP.

Ages	Treatments	Fertilizer levels				
	Cultivars	D1	D2	D3	D4	D5
28 DAP	V1	5.17ab	5.58ab	5.67ab	6.25ab	6.42ab
	V2	5.47ab	5.08ab	5.67ab	6.92a	6.42ab
	V3	5.00ab	5.83ab	5.67ab	6.92a	5.83ab
	V4	4.75b	5.50ab	5.67ab	5.42ab	6.50ab
35 DAP	V1	6.7ab	7.17ab	7.08ab	7.75ab	8.17ab
	V2	6.75ab	6.5b	7.17ab	8.75a	8.17ab
	V3	6.5b	7.25ab	7.92ab	8.17ab	7.25ab
	V4	6.67ab	6.92ab	7.00ab	7.25ab	8.08ab

Note. The same letters in each column indicate nonsignificant differences among the means by using Tukey's test; DAP = days after planting.

Table 4. Maize cultivars and fertilizer levels interaction effects on the stem diameter at the age of 14, 21, 28, 35, and 42 DAP.

Ages	Treatments	Fertilizer levels				
	Cultivars	D1	D2	D3	D4	D5
14 DAP	V1	0.13abc	0.19abc	0.18abc	0.24ab	0.20abc
	V2	0.09c	0.09c	0.13abc	0.22	0.14abc
	V3	0.15abc	0.14abc	0.18abc	0.25a	0.16abc
	V4	0.11bc	0.10c	0.10c	0.16	0.15abc
21 DAP	V1	0.32abc	0.47abc	0.4abc	0.54abc	0.54abc
	V2	0.27bc	0.26c	0.28bc	0.59ab	0.46abc
	V3	0.32abc	0.42abc	0.48abc	0.64a	0.42abc
	V4	0.28bc	0.28bc	0.34abc	0.37abc	0.48abc
28 DAP	V1	0.55abc	0.70abc	0.58abc	0.95abc	0.98abc
	V2	0.43de	0.39e	0.51cde	1.05ab	0.85abc
	V3	0.51cde	0.77abc	0.76abc	1.07a	0.73abc
	V4	0.43de	0.49cde	0.54bcd	0.63abc	0.86abc
35 DAP	V1	0.82b	1.09ab	0.88ab	1.27ab	1.30ab
	V2	0.69b	0.65b	0.79ab	1.60a	1.25ab
	V3	0.69b	1.05ab	1.10ab	1.42ab	1.02ab
	V4	0.66b	0.77b	0.94ab	1.02	1.23ab
42 DAP	V1	0.94b	1.25ab	1.04ab	1.35ab	1.42ab
	V2	0.82b	0.78b	0.95b	1.78a	1.44ab
	V3	0.80b	1.18ab	1.18ab	1.53ab	1.11ab
	V4	0.84b	0.90b	0.99ab	1.19ab	1.36ab

Note. The same letters in each column indicate nonsignificant differences among the means by using Tukey's test; DAP = days after planting.

Cultivar and fertilization interaction effects on soybean

The intercropping system of maize-soybean cultivars Exotic (maize) + Detap-1 (soybean) with 25% of the recommended dose of inorganic fertilizer + 30 t/ha of organic fertilizer had the tallest plant height (cm) in soybean (Table 5). This may be due to the varied genetic makeup of the genotypes affecting the plant's ability to absorb nutrients and adapt to the environment. Haitami *et al.'s* (2021) findings revealed that soybean cultivar Detap-1 can adapt to various types of land, including lands with limited water availability. It offers flexibility for cultivation in diverse locations with varying soil conditions. Additionally, soybean cultivar Detap-1 is well-

Table 5. Soybean cultivars and fertilizer levels interaction effects on the plant height at the age of 14, 21, 28, 35, and 42 DAP.

Ages	Treatments	Fertilizer levels				
	Cultivars	D1	D2	D3	D4	D5
14 DAP	V1	13.62ab	12.33ab	11.97ab	11.43ab	13.04ab
	V2	12.25ab	10.78ab	12.19ab	12.44ab	14.17a
	V3	10.43b	11.18ab	11.13ab	10.27b	12.55ab
	V4	11.90ab	11.33ab	11.52ab	10.78ab	12.28ab
21 DAP	V1	15.14abcd	16.09abc	17.21a	15.94abcd	16.08abc
	V2	16.36ab	14.48abcd	16.09abc	15.69abcd	17.61a
	V3	13.04bcd	12.82cd	13.54bcd	14.40bcd	13.45bcd
	V4	12.67d	13.21bcd	13.66bcd	13.14bcd	13.58bcd
28 DAP	V1	21.88abc	21.67abc	24.38a	23.20abc	23.03abc
	V2	21.73abc	20.38abc	24.14a	23.89ab	24.72a
	V3	17.79bc	19.88abc	20.28abc	22.64abc	19.88abc
	V4	17.33c	19.03abc	21.38abc	19.23abc	21.42abc
35 DAP	V1	28.98abc	30.63abc	34.94ab	31.88abc	32.62abc
	V2	31.65abc	28.23abc	32.50abc	34.25ab	35.89a
	V3	23.88c	29.34abc	30.18abc	33.53ab	30.98abc
	V4	26.68bc	26.56bc	31.95abc	27.84abc	31.95abc
42 DAP	V1	40.58abcd	40.73abcd	46.07ab	45.24ab	43.32abc
	V2	39.66abcd	38.55abcde	43.09abc	47.23a	46.19ab
	V3	28.09f	32.40cdef	33.12cdef	38.20abcdef	33.96cdef
	V4	28.74ef	29.90def	35.85bcdef	33.06cdef	40.00abcd

Note. The same letters in each column indicate nonsignificant differences among the means by using Tukey's test; DAP = days after planting.

suited for intercropping with maize, as it can thrive in more competitive environmental conditions (Permanasari *et al.,* 2021).

The interaction between soybean and fertilization significantly affects plant height in soybean plants, where not only the variety is determined, but also how the variety responds to fertilization (Salvagiotti *et al.*, 2008). In an intercropping system, where soybeans are grown in tandem with other crops, the interaction between crop cultivars and fertilization becomes more complex (Chen *et al.*, 2017). Competition for resources, such as light, water, and nutrients, can influence the final yield of individual crop plants. The selection of adaptive soybean cultivars and proper fertilization are essential to achieve the maximum yield in the intercropping system (Bekele *et al*., 2016).

In intercropping systems, competition for nutrients between maize and soybean plants is inevitable. The combination of 25% of the recommended inorganic fertilization + 30 t/ha of compost, gave the best results and increased plant height (cm) in soybeans. A combination of organic and inorganic fertilization with appropriate doses ensures that soybeans get enough nutrients to support the plant height and other growth traits (Khamparia *et al.,* 2018). Inorganic fertilizers provide a source of quickly absorbed nutrients; however, with the absence of organic fertilizers, the soil can lose its ability to store nutrients in the long term and help maintain the availability of nutrients on a sustainable basis (Ilahi *et al.,* 2020). Larger maize plants often dominate nutrient uptake. The use of inorganic fertilizers can supply and provide essential nutrients quickly for soybean plants, while organic fertilizers ensure long-term soil nutrient stability, reducing the effects of competition between maize and soybean (Baghdadi *et al.,* 2018). The intercropping promotes the highest growth of soybeans by minimizing nutrient deficiencies due to competition between both crops.

The maximum number of productive branches in soybean (21, 28, and 35 HST) emerged in the maize-soybean cultivars intercropping of Exotic (maize) + Detap-1 (soybean) with 25% of the inorganic recommended fertilizer + 30 t/ha of organic fertilizer (Table 6). The results showed a mutual relationship existed between the crop cultivars and the fertilizer dosage and type used. The soybean cultivar Detap-1 is a known type to best adapt to dry land conditions, which directly affects the number of branches (Sri, 2022). The genetic makeup of the cultivar Detap-1 allows for more optimal vegetative growth, including more branches, even in non-favorable environmental conditions.

The soybean cultivar Detap-1 displayed an excellent response to balanced fertilization, especially in intercropping with maize. The combination of 25% of the recommended inorganic fertilizer + 30 t/ha of organic fertilizer remarkably increased the number of branches in Detap-1 compared with other cultivars. This is because cultivar Detap-1 can absorb nutrients more efficiently, which supports vegetative growth and promotes more branch formation. In intercropping systems, the competition for nutrients between soybean and maize crops can alter the branching in soybean plants (Liu *et al.,* 2017). Applying the optimal fertilization dose helps soybean plants to compete more effectively with the maize crop (Yong *et al.,* 2018). Cultivars more tolerant of competition may optimize the number of branches through more efficient nutrient use, while less adaptive cultivars may experience a reduced number of branches due to competitive pressure from maize.

CONCLUSIONS

The interaction between maize-soybean intercropping and fertilizer doses has a significant impact on the morphological growth of maize and soybean plants. The results showed maize cultivar Exotic and soybean cultivar Detap-1, using 25% of the recommended dose of inorganic fertilizer

Table 6. Soybean cultivars and fertilizer levels interaction effects on the number of productive branches at the age of 14, 21, 28, 35, and 42 DAP.

Ages	Treatments	Fertilizer levels				
	Cultivars	D1	D2	D3	D4	D5
14 DAP	V1	13.62ab	12.33ab	11.97ab	11.43ab	13.04ab
	V2	12.25ab	10.78ab	12.19ab	12.44ab	14.17a
	V3	10.43b	11.18ab	11.13ab	10.27b	12.55ab
	V4	11.90ab	11.33ab	11.52ab	10.78ab	12.28ab
21 DAP	V1	15.14abcd	16.09abc	17.21a	15.94abcd	16.08abc
	V2	16.36ab	14.48abcd	16.09abc	15.69abcd	17.61a
	V3	13.04bcd	12.82cd	13.54bcd	14.40bcd	13.45bcd
	V4	12.67d	13.21bcd	13.66bcd	13.14bcd	13.58bcd
28 DAP	V1	21.88abc	21.67abc	24.38a	23.20abc	23.03abc
	V2	21.73abc	20.38abc	24.14a	23.89ab	24.72a
	V3	17.79bc	19.88abc	20.28abc	22.64abc	19.88abc
	V4	17.33c	19.03abc	21.38abc	19.23abc	21.42abc
35 DAP	V1	28.98abc	30.63abc	34.94ab	31.88abc	32.62abc
	V2	31.65abc	28.23abc	32.50abc	34.25ab	35.89a
	V3	23.88c	29.34abc	30.18abc	33.53ab	30.98abc
	V4	26.68bc	26.56bc	31.95abc	27.84abc	31.95abc
42 DAP	V1	40.58abcd	40.73abcd	46.07ab	45.24ab	43.32abc
	V2	39.66abcd	38.55abcde	43.09abc	47.23a	46.19ab
	V3	28.09f	32.40cdef	33.12cdef	38.20abcdef	33.96cdef
	V4	28.74ef	29.90def	35.85bcdef	33.06cdef	40.00abcd

Note. The same letters in each column indicate nonsignificant differences among the means by using Tukey's test; DAP = days after planting.

combined with 30 t/ha of organic fertilizer, exhibited the maximum plant height, leaf count, and stem diameter in maize across various stages of growth. Similarly, for soybeans, the combination of 25% of the recommended dose of inorganic fertilizer with 30 t/ha of organic fertilizer resulted in remarkable vegetative growth, including plant height and number of productive branches. Further research is essential to explore the long-term impact of different organic and inorganic fertilization, particularly focusing on soil health and nutrient uptake over multiple growing seasons.

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