



Cucumber-Peanut Intercropping: The Effects on Vegetative Growth and Yield Productivity

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Abstract: Intercropping is acknowledged as an effective agricultural intensification strategy for limited land. Planting time is an important factor in intercropping systems because it may intensify canopy overlap and shading, particularly because both crops rely on the C3 photosynthetic pathway, potentially reducing growth and yield. This study examined the effect of different planting times for cucumber (*Cucumis sativus* L.) and peanut (*Arachis hypogaea* L.). The study was conducted from October 2023 to February 2024 with a one-factor randomized block design. Five treatments were applied: simultaneous planting and cucumber planting at 1, 2, 3, and 4 weeks after peanuts, each replicated five times. Several data were analyzed using analysis of variance (F-test), followed by Tukey's HSD test at the 5% significance level. This study confirms that differences in planting time between cucumbers and peanuts significantly affect soil macronutrient dynamics, growth and production, and land use efficiency. Soil macronutrient analysis showed that simultaneous planting (P1) resulted the highest soil nitrogen increase (0.38%). However, this treatment also caused a reduction in phosphorus to 15.15 mg per 100 g of soil and potassium to 13.48 mg per 100 g of soil. In contrast, excessive delay (P5) caused nitrogen to drop to 0.11% and phosphorus to decline to 14.19 mg per 100 g soil, despite potassium remaining relatively high (17.87 mg per 100 g of soil). Simultaneous planting produced the highest vegetative growth of cucumber, with an average of 40.68 leaves per plant, the greatest fruit length (22.16 cm), individual fruit weight (414.55 g), and total fruit weight per plant (2498.39 g). Delaying cucumber planting resulted in the lowest value of 828.45 g in P5. The highest pod weight was recorded in P1 at 62.46 g per plant. In contrast, planting cucumbers one week after peanuts (P2) resulted in the lowest peanut yield, at only 47.14 g per plant. All treatments achieved LER values greater than 1, confirming the superiority of intercropping over monoculture. The highest LER was obtained in P1 (1.61). In conclusion, simultaneous planting of cucumbers and peanuts provides the most optimal balance between soil nutrient utilization, crop growth, yield, and land use efficiency. Therefore, synchronized planting time is a key management strategy for improving productivity and sustainability in cucumber-peanut intercropping systems under limited land conditions.

Keywords: Intercropping system; Land-use efficiency; Monoculture system; Planting time

Introduction

The timing of planting is a crucial element in intercropping system as it plays a role in a reducing competition between crops cultivated simultaneously.

This concept is closely related to the resource partitioning theory, Dong et al. (2018) state that differences in time, space, or resource use can reduce interspecific competition by allowing crops to exploit ecological niches more efficiently. This coheres with

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Willey (1979) study, reporting that planting time can reduce competition between crops as it minimizes overlapping critical growth phases. Plant sensitivity to competition varies at each growth phase, from germination, vegetative growth, flowering, to yield formation. In this regard, planting time is a determining factor in successful production (Aksarah et al., 2022).

In practice, determining the right planting time is a crucial strategy for minimizing negative interactions, such as competition for light, water, and nutrients, which prevail in intercropping systems (Sullivan, 1998). This phenomenon is explained by Sadras et al. (2017) who emphasize that crops are most vulnerable to resource limitation during specific growth stages. Competition during critical phases can decrease vegetative growth and crop yields. Therefore, managing planting time is required to regulate the distribution of resource requirements so that both crops can grow optimally (Smith & Francis, 1986).

In addition to planting timing, plant combinations in intercropping need to be based on several aspects, such as differences in root system depth, photosynthetic pathway type (C3 or C4), growth rate, and non-overlapping nutrient requirements (Gomez & Gomez, 1984). These considerations are closely linked to the competition-complementarity theory. Adhikari et al. (2018) suggest that well-selected crop combinations can shift plant interactions from competition toward complementarity. An ideal plant combination will maximize the use of vertical and horizontal space, as well as extend the period of light and nutrient utilization in the field (Lithourgidis et al., 2011).

One appealing combination to investigate is the intercropping of cucumber (*Cucumis sativus* L.) and peanut (*Arachis hypogaea* L.). Both plants have taproot systems, although those different depths. Cucumbers tend to have shallower roots than peanuts, allowing for complementary nutrient absorption. However, both plants rely on the C3 photosynthesis pathway, meaning they require relatively high light levels (Zhen et al., 2021). A common problem in this system is related to canopy architecture and light interception, where the wide canopy and large leaves of cucumber can shade the shorter peanut plants. Excessive shade can inhibit peanut photosynthesis, reduce pod formation, and ultimately reduce yields (Matheus, 2020). In this context, replanting time is crucial to reduce canopy overlap during critical growth stages.

In intercropping, planting timing is a strategic initiative to exploit the differences in critical phases between plants while minimizing competition (Willey, 1979). The critical phase refers to the growth period during which a plant becomes most sensitive to resource shortages, such as during early canopy formation or early flowering (Anjum et al., 2017). When the critical

phases of both plants overlap, competition will be intensified, potentially reducing productivity (O'Brien et al., 2017). In contrast, when the phases are separated temporarily, resource utilization becomes significantly more efficient, resulting in more optimal growth.

Furthermore, in legume-based intercropping systems, such as cucumber-peanut combinations, interactions may also involve facilitation mechanisms, particularly biological nitrogen fixation by legumes. However, the effectiveness of this facilitation depends on favorable early growth conditions for the legume. If peanut plants experience severe competition during early growth due to inappropriate planting time, their physiological plasticity and nitrogen-fixing capacity may be constrained, thereby limiting their potential contribution to the system.

Previous research has shown that combining crops with different root types and planting times, when properly managed, can significantly increase the Land Equivalent Ratio (LER) (Lithourgidis et al., 2011). An LER greater than 1 indicates that intercropping is more efficient than monoculture, both in terms of yield and resource utilization.

Against this background, this study investigates the effect of planting time on the growth and yield of cucumber and peanut plants in an intercropping system. This research seeks to evaluate alternative, more efficient, and sustainable cultivation solutions, particularly for farmers who rely on intercropping as an agricultural intensification strategy on limited land. This study also aims to expand the literature on planting time management in intercropping systems involving horticultural crops and legumes. Finally, it is devoted to expanding the literature on environmentally friendly cultivation technologies.

Method

Research Location and Time

This research was conducted over five months, from October 2023 to February 2024 in the agricultural area of the Miftahul Ulum Islamic Boarding School, located in the Amal Beach area of Tarakan City, North Kalimantan Province. It was selected based on the availability of adequate land and institutional and support.

Research Design

This study used a one-factor Randomized Block Design (RBD) to examine the effect of planting time in an intercropping system on the growth and production of cucumbers and the production of peanuts. The factor under investigation was the planting time of cucumbers relative to peanuts, which consisted of five treatments, namely: P1 (cucumbers and peanuts planted

simultaneously), P2 (cucumbers planted 1 week after peanuts), P3 (cucumbers planted 2 weeks after peanuts), P4 (cucumbers planted 3 weeks after peanuts), and P5 (cucumbers planted 4 weeks after peanuts). Each treatment was repeated five times, resulting in a total of 25 experimental units. Each experimental unit involved 8 cucumber plants with 4 samples and 32 peanut plants with 4 samples, leading to a total of 100 plants for each commodity (Figure 1). For the monoculture, we used the same pattern as intercropping, but it was repeated three times (Figure 2).

prepared for intercropping. Fertilization was carried out with both organic and inorganic fertilizers. Organic fertilizer obtained from chicken manure was applied at a rate of 10 tons per hectare and applied evenly across the plot. The inorganic fertilizer involved the application of NPK 16:16:16 at a dose of 125 kg per hectare, applied around the root zones. For cucumber plants, NPK 16:16:16 fertilizer was applied at 14 and 35 days after planting. Meanwhile, for peanuts, it was applied at 21 and 28 days after planting. Planting was carried out directly on the seedbed following the planting time treatments. Two seeds were planted 2–3 cm deep in the soil. The planting distance was set at 50 cm x 40 cm for cucumbers and 20 cm x 20 cm for peanuts, with two seeds placed per hole.

Maintenance procedures included installing stakes, replanting, weeding, and pest and disease control. Since cucumbers are a vining species, staking was done one week after planting. Replanting was performed two weeks after planting to replace any seeds that did not germinate. Weeding and ridge trimming were carried out at 6 weeks after planting for peanuts to improve soil aeration and stimulate root growth. Irrigation was provided in the morning and evening on a daily basis, especially during the initial growth phase (1–2 weeks). Once the cucumber plants reached the flowering phase, irrigation frequency was reduced to every other day and was entirely discontinued during rainfall. Harvesting was carried out according to the harvest age of each plant. Peanuts were harvested at 100 days after planting by carefully uprooting the entire plant to avoid leaving any pods in the soil, while cucumbers were harvested at 75 to 95 days after planting, depending on the plant maturity.

Data Analysis

The analysis used to test the research results was the F-test followed by the Tukey’s Honestly Significant Difference (Tukey’s HSD) test at the 5% significance level.

Results and Discussion

Soil Analysis

Analysis of soil macronutrient content before and after the peanut-cucumber intercropping treatment exhibited differences in nitrogen, phosphorus, and potassium content. Before the study, nitrogen content was relatively low (0.12%), phosphorus was high (18.86 mg per 100 g of soil), and potassium was moderate (16.72 mg per 100 g of soil). Subsequent to the treatment, each combination of cucumber and peanut planting times triggered different responses. In simultaneous planting, nitrogen in the soil increased sharply (0.38%), but

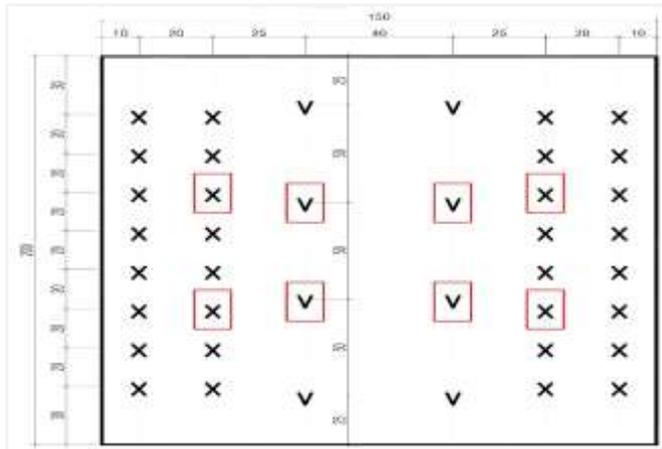


Figure 1. Intercropping (Description: X = Peanuts; V = Cucumber; Red Box = Sample)

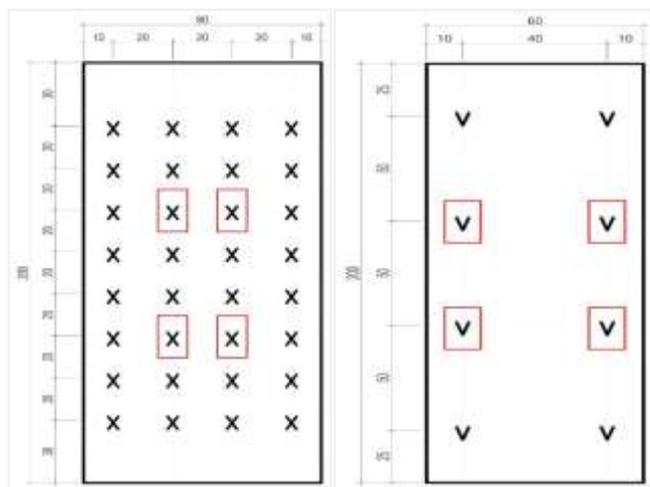


Figure 2. Monoculture (Description: X = Peanuts; V = Cucumber; Red Box = Sample)

Research Procedure

Prior to planting, the experimental site was prepared by clearing weeds, shrubs, and previous crop residues. The soil was tilled to improve aeration and assist cultivation. A total of thirty-one plots were created, including six plots for monoculture. Three plots measuring 0.8 m x 2 m for peanuts and three plots measuring 0.6 m x 2 m for cucumber. Twenty-five plots, each measuring 1.3 m x 2 m, or 2.6 m² per plot, were

phosphorus decreased to 15.15 mg per 100 g of soil, and potassium decreased to 13.48 mg per 100 g of soil.

Planting treatment one week after peanuts reduced nitrogen by 0.17%, phosphorus increased to 17.44 mg per 100 g of soil, but potassium was lower (12.49 mg per 100 g of soil). With a two-week delay, nitrogen relatively increased to 0.18%, phosphorus remained stable (16.85 mg per 100 g of soil), and potassium increased significantly to 18.56 mg per 100 g of soil. Cucumbers planted three weeks after peanuts produced the highest

phosphorus (18.88 mg per 100 g of soil), with potassium remaining high (18.38 mg per 100 g of soil), despite an increase in nitrogen to 0.16%. In contrast, after a four-week treatment, nitrogen decreased drastically to 0.11%, phosphorus reached its lowest point (14.19 mg per 100 g of soil), while potassium remained high (17.87 mg per 100 g of soil). This pattern demonstrates that the planting time of cucumbers affects nitrogen and phosphorus content and significantly influences potassium content.

Table 1. Analysis of Nutrient Content in Soil

Description	Nitrogen	Phosphor	Potassium
Before treatment	0.12±0.01	18.86±0.07	16.72±0.13abc
Simultaneous planting between crops	0.38±0.38	15.15±0.11	13.48±0.04bc
1-week gap between experimental plants	0.17±0.08	17.44±0.03	12.49±0.06c
2-week gap between experimental plants	0.18±0.03	16.85±0.07	18.56±0.07a
3-week gap between experimental plants	0.16±0.06	18.88±0.18	18.38±0.08a
4-week gap between experimental plants	0.11±0.10	14.19±0.06	17.87±0.12ab

Note: Numbers followed by different letters indicate a significant difference based on the analysis of significant difference test at a 5% confidence level. Values with the same letter are not significantly different, while those with different letters indicate a significant difference.

The research results demonstrate that varying planting times for cucumbers and peanuts in an intercropping system affect the post-harvest soil nitrogen (N), phosphorus (P), and potassium (K) content. These differences not only corroborate the physiological needs of plants at specific growth stages but also indicate optimal interactions between root systems, soil microbial activity, and the level of interplant competition. According to Su et al. (2018), plant interactions and temporal differences in growth stages regulate the transformation and redistribution of nutrients in the soil. In addition, Zhang et al. (2017) mention that in intercropping systems, these processes are strongly mediated by rhizosphere interactions and microbial dynamics.

In the simultaneous planting treatment, a significant increase in soil nitrogen content (0.38%) was identified, compared to the initial condition (0.12%). This highlights the pivotal role of peanuts as a legume capable of contributing to nitrogen fixation through symbiosis with *Rhizobium*. This finding affirms the assertion of Nasar et al. (2024), who stated that integrating legumes into intercropping systems can enrich soil nitrogen. However, the decrease in phosphorus and potassium in this treatment indicates that these two elements are highly critical during the early vegetative growth phase of peanuts and cucumbers, which leads to an imbalanced accumulation of these three essential nutrients. This condition is consistent with Xue et al. (2016) who state that simultaneous crop establishment increases competition for immobile nutrients such as P and K during early growth stages.

With a one-week delay, nitrogen decreased to 0.17%, but phosphorus increased to 17.44 mg per 100 g of soil. This is indicative of the fact that the delayed planting gave the peanuts time to develop their root systems and release exudates capable of dissolving bound phosphate, making phosphorus more available. Wang et al. (2025) stated that legume root exudates, including organic acids, can increase phosphorus availability. Nevertheless, potassium decreased, indicating intensive uptake by the plants in the active growth phase. This phenomenon aligns with Vives-Peris et al. (2020) who emphasize the role of root exudates in altering soil chemical conditions to improve nutrient solubility.

The treatments involving two-week and three-week delays resulted in different patterns. Phosphorus remained relatively stable, while potassium reached its highest value (18.38–18.56 mg per 100 g of soil). This confirms that delaying cucumber planting by 2–3 weeks augments the advantage of more optimal root distribution, preventing direct competition for nutrients between the experimental plants. According to Ebbisa (2022), differences in planting time in intercropping contribute to root stratification, which subsequently increases the bioavailability of K and P. In addition, the findings of Schut et al. (2023) derived through the RC-KP dynamic model report that the time and distribution of plant symbiosis significantly influence P and K uptake. This outcome supports the root stratification theory, whereby temporal separation promotes complementary nutrient uptake (Griffiths & York, 2020).

However, under the four-week planting delay, the phosphorus content decreased sharply to 14.19 mg per

100 g of soil. In contrast, nitrogen levels dropped back to 0.11%, despite potassium remaining relatively substantial. This finding demonstrates that excessive delay causes cucumbers to enter a growth phase when most of the existing phosphorus has either been absorbed by peanuts or has become re-fixed into soil minerals. In this context, Rusu et al. (2025) emphasize that, in the absence of additional management practices, soil phosphorus availability tends to decline under long-term conservation mechanisms. This accounts for the marked decline in phosphorus in this treatment.

From a plant physiological viewpoint, nitrogen is primarily required for vegetative tissue formation, while phosphorus is essential for root development and energy (ATP) production. Potassium plays a key role in photosynthate transport, osmoregulation, and fruit formation. On the whole, planting time significantly determines how the nutrient uptake balance occurs. (Kumar et al., 2020) argue that planting or fertilization timing is closely related to the uptake efficiency of nitrogen and phosphorus, with inaccurate timing potentially reducing productivity. Lopez et al. (2017) state that growth-stage-specific nutrient demand requires optimal uptake.

Practically, simultaneous planting indeed increases soil nitrogen, although it leads to reduced phosphorus and potassium. Conversely, a two- to three-week delay is found to be more effective in maintaining nutrient balance, as phosphorus and potassium remain high despite relatively lower nitrogen. This finding supports the report by Neves et al. (2022), which reports that differences in plant growth phases influence soil stoichiometry (C:N:P) as well as the quality of organic and mineral nutrients. In addition, Shahid et al. (2016) mention that balanced elemental ratios are essential for sustaining soil fertility and crop productivity.

Thus, the NPK analysis results indicate that the interaction between cucumber and peanut planting times affects soil fertility differently for each element. Planting strategies that consider optimal intervals can improve soil nutrient use efficiency, stimulate better plant growth, and serve as an essential cornerstone for sustainable intercropping systems. This conclusion is in line with Altieri et al. (2017) who emphasizes optimizing biological interactions to enhance productivity without increasing external inputs.

Cucumber Growth and Yield

The number of cucumber leaves was observed at 40 days after planting by counting the number of leaves on each sample plant. The number of cucumbers per plant was quantified based on the total fruit produced by each sample plant. To determine the fruit size, the fruit length was measured from the base to the tip using a ruler after the fruit had been harvested. At the same time, the fruit diameter was measured at the center of the fruit using a vernier caliper. The cucumber weight per plant was measured by adding up the total weight of the fruit produced by each sample plant, and was reported in grams.

The analysis confirmed that the timing of cucumber planting significantly affected vegetative growth and yield. The highest number of leaves was documented in the simultaneous planting treatment with peanuts, at 40.68, which was significantly different from that in the other treatments, which ranged from 22–25 leaves. Fruit length was also the greatest in the simultaneous treatment (22.16 cm), while the lowest was recorded in the two-week delay (17.58 cm). Fruit girth showed less variation, with the highest figure found in the four-week delay (18.01 cm) and the lowest in the two-week delay (16.45 cm).

Table 2. Cucumber Growth and Yield

Treatments in Cucumber Planting Time	Number of Cucumber Leaves	Cucumber Fruit Length (cm)	Cucumber Fruit Girth (cm)	Individual Cucumber Fruit Weight (gr)	Cucumber Fruit Weight per Plant (gr)
Simultaneous planting with peanuts	40.68±0.11a	22.16±0.01a	17.57±0.02ab	414.55±0.04a	2498.39±0.14a
1 week after peanut planting	25.26±0.1b	20.67±0.02ab	16.77±0.01bc	354.94±0.06b	1507.8±.1b
2 weeks after peanut planting	22.76±0.03b	17.58±0.04d	16.45±0.01c	220.59±0.02c	882.35±0.02c
3 weeks after peanut planting	23.54±0.05b	18.62±0.03cd	17.14±0.02abc	219.7±0.01c	878.8±0.01c
4 weeks after peanut planting	22.96±0.06b	19.33±0.02bc	18.01±0.01a	207.11±0.04c	828.45±0.04c

Note: Values followed by different letters indicate a significant difference according to the significant difference test at the 5% significance level. Values sharing the same letter indicate an insignificant difference, whereas those with different letters show a statistically significant difference.

Fruit weight per cucumber was significantly affected by the treatment; the simultaneous treatment produced the heaviest fruit (414.55 g), while the four-week-delay treatment yielded fruit with a lower weight, reaching only 207.11 g. A similar pattern was evident in fruit weight per plant: the simultaneous treatment

produced the highest yield, at 2498.39 g per plant, almost three times that of the four-week treatment (828.45 g per plant). Overall, the simultaneous planting treatment with peanuts provided the best vegetative growth (number of leaves) as well as the highest yield (length, individual weight, and total weight per plant). By

contrast, delayed planting, especially beyond two weeks, significantly reduced growth and yield.

The results showed that the timing of cucumber planting relative to peanuts significantly determines the optimal growth and production. Simultaneous planting resulted in superior vegetative growth (the highest number of leaves) and yield, both in terms of individual fruit weight and total weight per plant. This finding supports the idea that synchronizing growth phases between plants in intercropping systems can minimize competition during critical phases while enhancing resource utilization efficiency (Nasar et al., 2024). Temporal synchronization reduces the overlap of peak resource demand, thereby enhancing productivity (Dolezal et al., 2020).

The high number of leaves in the simultaneous treatment indicates that the cucumbers received more suitable environmental conditions, in terms of light, water, and nutrient availability. Leaves are the primary photosynthetic organs, so a greater number of leaves will stimulate better assimilate accumulation, which is then allocated to the generative organs, particularly the fruit (Schut & Reymann, 2023). Delaying planting by 1–4 weeks resulted in a drastic reduction in the number of leaves, indicating stunted vegetative growth of the cucumbers. Presumably, by the time the cucumbers began to grow, peanuts had already taken over the root space and canopy, triggering intense competition for light and nutrients.

Fruit length and girth were also influenced by the treatment. The highest fruit length was achieved during simultaneous planting (22.16 cm), while in treatments involving two- and three-week delays after peanut planting, fruit length decreased significantly (17.58–18.62 cm). However, fruit girth did not follow a uniform pattern. In the four-week treatment, fruit girth was the greatest (18.01 cm), despite relatively low fruit weight and length. This indicates a morphological response of cucumber fruit to assimilate limitation, where longitudinal growth is inhibited while lateral growth is relatively maintained (Ferion et al., 2025).

Individual and cumulative fruit weights per plant provided the most observable parameters for determining the differences between treatments. Simultaneous planting yielded an individual weight of 414.55 g and a total of 2498.39 g per plant, significantly higher than those in the delayed planting treatments, which only ranged from 207 g–354 g per fruit and 828 g–1507 g per plant. This difference implies intense competition in the delayed planting treatments, especially because cucumbers reached the growth phase when peanuts had already developed rapidly and absorbed large amounts of nutrients and water. According to Ebbisa (2022), in intercropping systems, inappropriate planting timing can constrain the

resources essential for the secondary crops, gradually reducing productivity.

Besides competition, yield differences are also related to soil nutrient dynamics. As demonstrated in the previous nutrient analysis, simultaneous treatments stimulated higher levels of soil nitrogen, which directly supported the vegetative growth of cucumbers. Conversely, delayed planting forced cucumbers to grow in soil conditions with minimal nitrogen and phosphorus, thus inhibiting leaf and fruit growth. Clayton et al. (2024) confirmed that the timing of input application, including the utilization of natural nutrients by legumes, significantly influences the productivity of accompanying crops. This interaction is in line with Selim (2020), who emphasizes matching nutrient availability with crop demand to optimize growth.

Another ecophysiological factor that plays a critical role is root distribution. In simultaneous treatments, peanut and cucumber roots develop simultaneously, resulting in relatively balanced initial competition. However, with delayed planting, peanut roots are already established, deeper, and more extensive, obstructing newly emerging cucumbers from competing for nutrients and water. This finding is supported by research on soybean-corn intercropping, where differences in planting time affect root exploration patterns and ultimately the secondary crop yields (L. Li et al., 2022).

These results underline the importance of synchronized planting times in intercropping strategies. If the goal is to achieve high cucumber yields, simultaneous planting is the superior option. However, if peanuts are the dominant crop, delaying cucumber planting can reduce competition, albeit at the cost of lower cucumber productivity. In summary, Rusu et al. (2025) suggest that additional fertilization or adjusting plant spacing can mitigate the negative impacts of delayed planting. According to Capitanescu et al. (2017), this reflects the trade-off theory, where management decisions optimize one crop's performance while potentially constraining the other.

Peanut Yields

The results demonstrated that the treatments generated a significant effect on pod weight per peanut plant. The highest pod weight was obtained in P1, with an average of 62.46 g per plant. This treatment yielded significantly different results compared to other treatments. The lowest pod weight was found in treatment P2 (planting cucumbers 1 week after peanuts) with an average of 47.14 g per plant. Treatment P3, which involved planting cucumbers two weeks after peanuts, produced a pod weight of 59.69 g per plant, like that of P1. Meanwhile, in treatment P4 (3 weeks after

peanuts) and P5 (4 weeks after peanuts), the respective yields were 53.29 g and 57.57 g per plant.

Overall, the results showed that P1 and P3 treatments produced higher peanut yields than the other treatments. This suggests that synchronizing the early vegetative growth of the two plants contributes to optimal peanut yield. Conversely, P2 showed the lowest yield, indicating unfavorable competition during the early growth stage of peanuts.

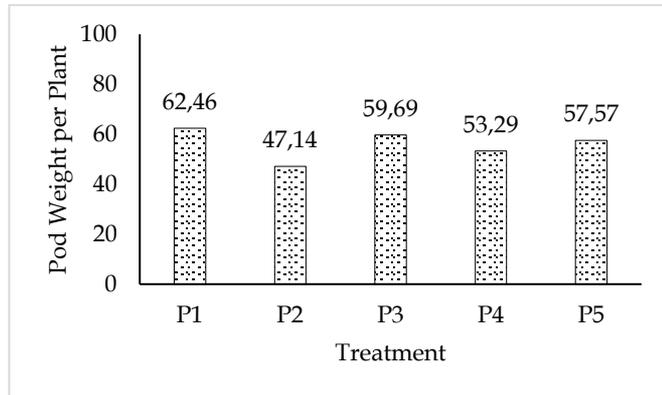


Figure 3. The production of peanut pod (Description: P1 = cucumbers planted simultaneously with peanuts; P2 = cucumbers planted one week after peanuts; P3 = cucumbers planted two weeks after peanuts; P4 = cucumbers planted three weeks after peanuts; and P5 = cucumbers planted four weeks after peanuts)

The results highlighted the differences in planting time between cucumbers and peanuts, which significantly affected the weight of peanut pods per plant. The highest pod weight was obtained from simultaneous planting (P1), while the lowest was observed in P2 treatment. This indicates that synchronizing plant growth phases in intercropping systems results in the efficient use of light, water, and soil nutrients. This outcome is consistent with Zörb et al. (2019), who explain that yield formation is highly sensitive to resource availability during specific reproductive stages.

Simultaneous planting allows both crops to adapt early, enabling their root systems and canopies to develop harmoniously. This reduces the dominance of one crop over the other and increases the efficient utilization of light and growing space (Qin et al., 2025). Conversely, planting cucumbers one week after peanuts (P2) causes an imbalance in growth phases, where the previously developed peanuts face sudden competition from growing cucumbers. This disrupts pod development and leads to reduced yield.

Interestingly, the two-week delay (P3) treatment resulted in fairly high pod weight, nearly equivalent to simultaneous planting. This may be because the peanuts had already progressed through the early growth phase,

deescalating competition for nutrients and light between crops. This aligns with research by Tang et al. (2024), which demonstrated that adjusting the planting time in an intercropping system can reduce competition while optimizing the yield of key components.

In treatments P4 and P5, pod yields were relatively lower than those in P1 and P3. Delaying cucumber planting by three and four weeks resulted in the peanuts entering the generative phase when the cucumbers were first planted. At this stage, peanuts require more nutrients for pod formation. The presence of cucumbers amplified competition and thus decreased pod yield (Zhang et al., 2024).

In addition, peanuts, as a legume, also contribute nitrogen through biological fixation. A balanced planting time can influence the ability of peanuts to provide nitrogen for their own growth and accompanying crops. Xu et al. (2020) explain that the interaction of legumes with non-legumes in intercropping systems hinges on the synchronization of growth phases, which influences soil nitrogen availability.

The results also reinforce the findings of Raza et al. (2020), who stated that adjusting the planting time in an intercropping context reduces competition and increases land use efficiency. This study has demonstrated that simultaneous planting and a two-week delay between crops result the most optimal yields.

Land Equivalent Ratio (LER)

LER is an index used to assess land use efficiency in intercropping systems. It is quantified based on the sum of the relative yields of the two crops in intercropping. Based on the graph, the highest LER marked at 1.61 was obtained in treatment P1. Statistically, this implies that land use efficiency in the cucumber-peanut intercropping system increases by 61% compared to monoculture. Treatment P3 (cucumber planted 2 weeks after peanuts) ranks second with LER of 1.16, followed by P2 and P5, which both achieved LER of 1.12, while the lowest value was found in P4 (1.06). All treatments showed values greater than 1, indicating that intercropping consistently provides advantages compared to monoculture. However, differences between treatments demonstrate the important role of synchronization of planting times. Treatment P1 showed superior results because both plants were able to utilize resources in the early growth phase without competitive interference. Conversely, delaying planting time, particularly in P4, leads to asynchronous growth, since one plant has already developed while the accompanying crop remains in the vegetative phase, thus reducing resource utilization efficiency. These results demonstrate that LER is influenced not only by the type of intercropped plant but also by the

appropriate planting time, which determines the nature of competition and complementarity between plants.

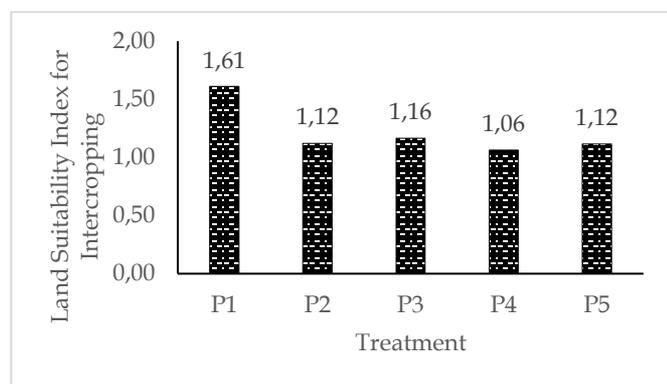


Figure 4. Land Equivalent Ratio (Note: An LER greater than 1 indicates a yield advantage from intercropping, an LER equal to 1 shows no advantage compared to monocropping, and an LER less than 1 signifies a yield disadvantage)

The consistent LER value of more than one across all treatments demonstrates that the cucumber-peanut intercropping system has advantages in increasing productivity per unit area compared to monoculture systems. This finding aligns with Stomph et al. (2020), who stated that intercropping always has the potential to increase land efficiency as long as crops are complementary. Furthermore, Dong et al. (2018) also emphasized that the advantages of intercropping are largely determined by the synchronization of growth between crops, which is documented in P1, leading to the highest LER in this study. Moving forward, Xu et al. (2020) argue that increased result from the differences in nutrient absorption, allowing the roots of different plants to complement each other in utilizing soil nutrients. This shows that synchronized planting times not only determine individual crop yields but also influence the LER.

Considering the peanut pod weight and cucumber fruit weight, this study makes it explicit that P1 not only produced the highest LER but also stimulated the optimal growth conditions for the experimental plants. In P1, peanuts produced 62.46 g/plant and cucumbers reached 2498.39 g/plant. This pattern indicates that synchronized planting times triggered ideal conditions for optimal growth for both crops, optimizing light, water, and nutrients availability without interference from competition. Thus, the simultaneous growth between peanut and cucumber contributes to the high LER. Shah et al. (2019) state that synchronizing crop development enhances the complementary use of environmental resources, thereby maximizing system productivity.

In contrast, in P2 (cucumbers planted one week after peanuts), a sharp decline in both peanuts (47.14 g/plant, the lowest) and cucumbers (1507.8 g/plant)

was discovered. This suggests that the short delay actually increased competition, as peanuts were already established in the early vegetative phase and thus dominated nutrient utilization, while newly planted cucumbers struggled to adapt. This reduced the productivity of both crops, and although the LER remained above 1 (1.12), the gains were insubstantial.

In P3, peanuts showed a high yield (59.69 g/plant), approaching P1, but cucumbers only produced 882.35 g/plant. This pattern indicates a trade-off: peanuts benefited from earlier adaptation to the environment, while cucumbers lagged and had to compete during the critical growth phase. Despite this, the LER remained quite high (1.16), indicating that intercropping remains more efficient than monoculture, but the greatest benefits were skewed towards peanuts. Dominant crops capture a larger share of assimilates and resources under competitive conditions (Li et al., 2020).

P4 and P5 showed increasingly asynchronous conditions. In P4, peanuts yielded only 53.29 g/plant and cucumbers yielded 878.8 g/plant. The LER value was also the lowest (1.06), indicating reduced land use efficiency. In P5, peanuts yielded 57.57 g/plant, while cucumbers only yielded 828.45 g/plant. The LER value (1.12) still indicated a relative advantage, but it was markedly lower than that in P1. This suggests that a greater planting interval results in lower growth synchronization, thereby depressing cucumber yields, even though peanuts remained relatively stable.

Overall, the synchronization pattern of peanut and cucumber yields remained consistent with the LER values. Treatment P1 generated maximum benefits in individual plant yield and LER. P2 through P5 proved that delaying the planting time created a trade-off between the two crops, with peanuts benefiting more than cucumbers. These results resonate with the basic concept of intercropping that the success of the system is affected by the inclusion of plant pairs and the planting time (Gebru, 2015).

From a practical angle, the results confirm that simultaneous planting time (P1) between cucumber and peanut is the superior strategy for gaining maximum productivity and land efficiency. Farmers need to consider this strategy to achieve high cucumber yields without sacrificing peanut yields. In addition, the strategy is proven to be gainful in raising LER by up to 61%. Therefore, synchronized planting times are a key priority in developing sustainable and gainful intercropping systems. Improving productivity through better management of biological interactions rather than increasing external input is emphasized by (Altieri et al., 2017).

Conclusion

This study confirms that differences in planting time between cucumbers and peanuts significantly affect soil macronutrient dynamics, growth and production, and land use efficiency. Soil macronutrient analysis showed that simultaneous planting (P1) resulted in the highest soil nitrogen increase (0.38%). However, this treatment also caused a reduction in phosphorus to 15.15 mg per 100 g of soil and potassium to 13.48 mg per 100 g of soil. In contrast, excessive delay (P5) caused nitrogen to drop to 0.11% and phosphorus to decline to 14.19 mg per 100 g of soil, despite potassium remaining relatively high (17.87 mg per 100 g of soil). These findings demonstrate that planting time strongly regulates nutrient availability, especially nitrogen and phosphorus. Simultaneous planting produced the highest vegetative growth of cucumber, with an average of 40.68 leaves per plant, the greatest fruit length (22.16 cm), individual fruit weight (414.55 g), and total fruit weight per plant (2498.39 g). Delaying cucumber planting resulted in the lowest value of 828.45 g in P5. The highest pod weight was recorded in P1 at 62.46 g per plant, followed closely by P3 at 59.69 g per plant. In contrast, planting cucumbers one week after peanuts (P2) resulted in the lowest peanut yield, at only 47.14 g per plant. Land Equivalent Ratio (LER) analysis further emphasized the importance of planting time synchronization. All treatments achieved LER values greater than 1, confirming the superiority of intercropping over monoculture. The highest LER was obtained in P1 (1.61), corresponding to a 61% increase in land use efficiency. In conclusion, simultaneous planting of cucumbers and peanuts provides the most optimal balance between soil nutrient utilization, crop growth, yield, and land use efficiency. Therefore, synchronized planting time is a key management strategy for improving productivity and sustainability in cucumber-peanut intercropping systems under limited land conditions.

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Author Contributions

Mardhiana contributed to the research conceptualization, methodology development, formal analysis, writing the initial draft, research supervision, and funding acquisition. Eko Hary Pudjiwati was responsible for the validation of research results, field investigation, data management, and the review and editing of the manuscript. Nurul Chairiyah facilitated the experiment, data curation, visualization of the research results, and preparation of the manuscript through the review and editing process. Junarius bin Yakobus supported the provision

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Conflicts of Interest

The authors declare no conflict of interest.

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