

Physiological responses and productivity of spinach (*Amaranthus tricolor* L.; Amaranthaceae) under monoculture and polyculture systems of urban home garden in Yogyakarta

Malika Azzahra¹, Siti Nurul Rofiqo Irwan^{1*}, Budiastuti Kurniasih¹

¹Department of Agronomy, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia

*Corresponding author: rofiqoirwan@ugm.ac.id

ABSTRAK

Bayam (*Amaranthus tricolor* L.) merupakan sayuran daun adaptif yang berpotensi dikembangkan pada ruang terbatas di pekarangan urban. Kajian mengenai perbedaan respons pertumbuhan dan produktivitas antara bayam hijau dan bayam merah pada sistem tanam monokultur maupun polikultur di pekarangan masih terbatas. Penelitian ini bertujuan untuk (1) menilai respons pertumbuhan dan hasil dua varietas bayam, yaitu bayam hijau dan bayam merah, pada sistem monokultur dan polikultur, serta (2) mengevaluasi efektivitas kedua sistem tersebut. Percobaan dilakukan di pekarangan wilayah Pilahan, Rejowinangun, Yogyakarta, pada Februari–Maret 2025 menggunakan Rancangan Acak Kelompok Lengkap (RAKL) faktorial 2×2 dengan tiga ulangan. Variabel yang diamati meliputi tinggi tumbuhan, jumlah daun, luas daun, biomassa, kandungan klorofil, dan produktivitas. Hasil menunjukkan bahwa sistem monokultur maupun polikultur tidak memberikan pengaruh signifikan terhadap sebagian besar parameter pertumbuhan dan produktivitas. Bayam hijau dan bayam merah menunjukkan adaptabilitas serta respons pertumbuhan yang relatif serupa pada kondisi panas perkotaan. Analisis Land Equivalent Ratio (LER) menunjukkan nilai 1,09 pada sistem polikultur, yang berarti peningkatan efisiensi penggunaan lahan sebesar 9% dibandingkan monokultur. Temuan ini menegaskan potensi penerapan sistem polikultur di pekarangan urban untuk meningkatkan efisiensi lahan dan produktivitas tumbuhan.

Kata kunci: efektivitas lahan, monokultur, polikultur

ABSTRACT

Spinach (*Amaranthus tricolor* L.) is an adaptive leafy vegetable suitable for cultivation in urban limited space of home garden (*pekarangan*). Studies comparing growth responses and productivity of green spinach and red spinach under monoculture and polyculture systems in *pekarangan* remain scarce. This study aimed to (1) assess growth responses and yield of green spinach and red spinach under monoculture and polyculture systems, and (2) assess the effectiveness of these systems. The experiment was conducted in *pekarangan* in Pilahan, Rejowinangun, Yogyakarta, from February to March 2025 using a 2×2 factorial Randomised Complete Block Design (RCBD) with three replications. Variables measured included plant height, leaf number, leaf area, biomass, chlorophyll content, and productivity. Results indicated that monoculture and polyculture systems did not significantly influence most growth and productivity parameters. Both spinach cultivars showed similar adaptability under urban hot conditions. Land Equivalent Ratio (LER) analysis revealed that polyculture achieved an LER of 1.09, reflecting a 9% increase in land-use efficiency compared to monoculture. These findings suggest polyculture has potential for application in urban *pekarangan* to enhance land-use efficiency and crop productivity.

Keywords: land-use efficiency; polyculture; sole cropping

INTRODUCTION

The utilisation of Indonesian home gardens, locally known as *pekarangan*, as household-scale food production spaces has become increasingly significant in urban areas, particularly in response to limited land availability and rising demand for fresh vegetables. *Pekarangan* are multifunctional landscapes that can be optimised to provide food

while simultaneously enhancing environmental aesthetics and contributing to urban cooling. The cultivation of short-cycle vegetables such as spinach is therefore a practical option. Spinach (*Amaranthus tricolor* L.) is recognised as an adaptive crop, easy to cultivate, and valued for its ornamental qualities due to the diversity of leaf colours, especially in green and red spinach (Sarker & Oba, 2020).

Spinach growth is influenced by environmental factors, notably light, temperature, and humidity. Its shallow root system and rapid growth rate render the crop sensitive to fluctuations in light intensity, particularly in *pekarangan* where shading from buildings and other vegetation is common (Yu et al., 2025). Cropping systems also play a decisive role in determining the effectiveness of *pekarangan* utilisation. Monoculture is widely practised owing to its relative simplicity, yet polyculture or mixed cropping can enhance spatial efficiency, small-scale ecosystem sustainability, and the aesthetic value of *pekarangan*.

Several studies on horticultural crops have demonstrated that mixed cropping patterns improve the utilisation of light and space, although plant responses may vary depending on the degree of interspecific competition. Kos et al. (2021) reported that mixed cropping increased spatial efficiency in *pekarangan*, while Ngcobo & Bertling (2024); Mahardika et al. (2025) highlighted that plant diversity within a single plot can enhance land-use efficiency and microecological balance. Martinez et al. (2024) further noted that variations in cropping systems may elicit different growth responses among vegetable species. Nevertheless, research on the physiological responses, growth, and productivity of green and red spinach under monoculture and polyculture systems in urban *pekarangan* remains limited, particularly studies employing the Land Equivalent Ratio (LER) to assess land-use effectiveness.

The Land Equivalent Ratio (LER) is a widely used index for evaluating land-use efficiency in mixed cropping relative to monoculture. An LER value greater than 1 indicates that polyculture systems utilise land more efficiently than monoculture systems within the same area (Willey, 1979). The present study was conducted to investigate the effects of monoculture and polyculture cropping systems on the physiological responses, growth, and productivity of green and red spinach in urban *pekarangan*. Furthermore, the study aimed to assess the effectiveness of land use in polyculture compared with monoculture through the application of the LER approach.

METHODOLOGY

The study was conducted from February to March 2025 in urban *pekarangan* in Pilahan, Rejowinangun, Yogyakarta (90–95 m above sea level). The research site exhibited microclimatic conditions characteristic of *pekarangan* in urban areas, with varying levels of shading among blocks due to surrounding buildings and vegetation. Light intensity was measured using a lux meter in the morning (07:00–08:00 WIB), midday (12:00–13:00 WIB), and afternoon (16:00–17:00 WIB) within each observation block to assess variations in light conditions among research plots. The main materials used included green spinach seeds (*Amaranthus tricolor* L. ‘Maestro’) and red spinach (*Amaranthus tricolor* L. ‘Mira’), goat manure fertiliser, and planting media consisting of a mixture of soil and manure at a ratio of 2:1. Watering was carried out twice daily in the morning and

afternoon according to the moisture condition of the planting media. In addition, goat manure fertiliser was applied once at the beginning of planting.

Experimental design

The study employed a 2×2 factorial Randomised Complete Block Design (RCBD) consisting of two factors, which are cropping system and spinach cultivars, each with three replications. The cropping systems consisted of monoculture and polyculture. Monoculture refers to the cultivation of a single spinach cultivar within one planting plot. Then, the polyculture system in this study refers to the simultaneous cultivation of two spinach cultivars, the green and red spinach, within the same planting plot as a cultivar mixture that allows competitive and complementary interactions among plants. Each experimental unit consisted of a 1.5×1.5 m planting bed with a 25 cm planting distance, yielding 36 plants per plot.

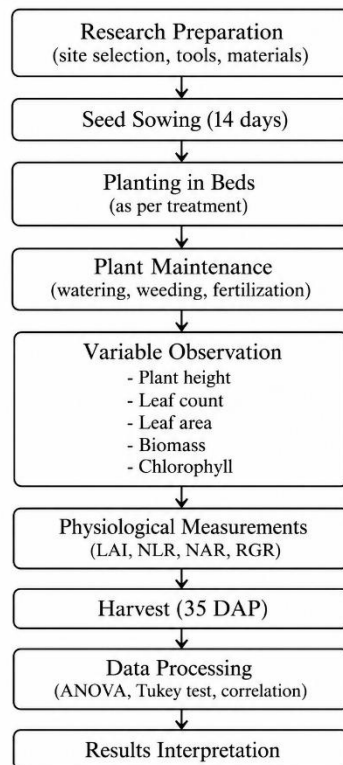


FIGURE 1. Flowchart in designing and completing this research

The research stages began with preparing planting media and planting beds, seed germination for approximately 7 days, transplanting seedlings into experimental plots, plant maintenance, light-intensity measurements, observation of growth and physiological variables, and data analysis. Plant maintenance included watering twice daily, manual weeding, and mechanical weed control. The research procedure flowchart is presented in FIGURE 1.

Observation and measurement of variables

The observed growth variables included plant height, leaf number, leaf area ratio (LAR), net assimilation rate (NAR), relative growth rate (RGR), chlorophyll content, and

plant productivity. Plant height observations were conducted at 14, 21, and 35 days after sowing (DAS) to represent the early vegetative, middle vegetative, and harvest phases of spinach growth according to the growth cycle of *Amaranthus tricolor*, which is generally harvested at 30–40 DAS (Rukmana, 2005). Destructive observations were conducted at 14 and 35 DAS to obtain initial and final growth data for plant growth analysis.

The number of leaves was counted manually on fully expanded leaves. Leaf area was measured using a digital image-based method with a Leaf Area Meter. Fresh weight was measured immediately after harvest using a digital balance, whereas dry weight was obtained after samples were oven-dried at 70°C until a constant weight was reached. LAR, NAR, and RGR values were calculated from plant growth analysis following Hunt (1990). Chlorophyll content was measured at 35 DAS using the spectrophotometric method described by Arnon (1949), as the leaves had developed optimally and the chlorophyll content was therefore more representative of the plants' photosynthetic capacity. Plant productivity was calculated based on the total fresh weight of plants at harvest.

Land-use efficiency in the polyculture system was analysed using the Land Equivalent Ratio (LER) to compare it with monoculture systems. The LER was calculated by comparing each cultivar's productivity in the polyculture system with its productivity in the monoculture system using the following equation.

$$LER = \frac{Y_{g,p}}{Y_{g,s}} + \frac{Y_{r,p}}{Y_{r,s}}$$

- $Y_{g,p}$ = productivity of green spinach in the polyculture system
- $Y_{g,s}$ = productivity of green spinach in the monoculture system.
- $Y_{r,p}$ = productivity of red spinach in the polyculture system
- $Y_{r,s}$ = productivity of red spinach in the monoculture system

An LER > 1 indicates that the polyculture system is more efficient at utilising land than the monoculture system (Willey, 1979).

Data analysis

The obtained data were analysed using two-way Analysis of Variance (ANOVA). If significant effects were observed, the analysis was continued using Tukey's post hoc test at the 95% confidence level in RStudio version 4.4.1 (R Core Team, 2024). In addition, a correlation analysis was conducted to assess relationships among growth and yield variables.

RESULT AND DISCUSSION

The results showed that monoculture and polyculture cropping systems elicited different responses in the growth of green and red spinach across several observed parameters. Plant height was measured at 14, 21, and 35 DAS to characterise plant growth dynamics from the early vegetative stage to the pre-harvest stage. Observation at 21 DAS was added to assess growth during the middle vegetative stage, thereby enabling a more comprehensive assessment of plant growth patterns. In general, plant height increased

with increasing plant age across all treatments. However, the analysis of variance showed that the cropping system did not significantly affect plant height.



FIGURE 2. Plant height at (a) 14 DAS and (b) 35 DAS

TABLE 1. Plant height (cm) of both green and red spinach on three different observation times

Treatment	Plant height (cm)		
	14 DAS	21 DAS	35 DAS
Planting system			
Sole cropping	5.10 a	8.10 a	34.83 a
Polyculture	5.20 a	9.09 a	29.29 a
Spinach cultivar			
Green spinach	5.72 p	9.52 p	35.62 p
Red spinach	4.58 q	7.67 q	28.50 p
Interaction	-	-	-
CV (%)	8.74	10.1	27.89

Values followed by the same letters within the same column indicate no significant difference based on Tukey's Honest Significant Difference (HSD) test at 95% confidence level. The symbol (-) indicates no interaction. DAS = days after sowing.

Based on **FIGURE 2** and **TABLE 1**, monoculture and polyculture systems did not significantly affect spinach plant height at 14, 21, and 35 DAS. The same letter notation in the cropping system treatments indicates that differences in cropping patterns did not cause significant differences in plant height. These results indicate that spinach growth remained relatively stable under both cropping systems throughout the vegetative phase.

Spinach type significantly affected plant height at 14 and 21 DAS, where green spinach exhibited greater plant height than red spinach. This difference indicates variation in early growth rates associated with the morphological characteristics of each variety. However, at 35 DAS, the difference in plant height was no longer significant, indicating that red spinach growth increased in the subsequent stage and approached that of green spinach.

The coefficient of variation (CV) at 35 DAS was 27.89%, indicating high variability in plant growth across observation blocks. This variation was associated with differences in shading levels and light interception across research plots. According to Nájera et al. (2023), differences in light conditions within heterogeneous cultivation environments can affect physiological responses and plant growth. High environmental variability may reduce the sensitivity of statistical tests, so that some differences in treatment means do not reach statistical significance. Differences in light conditions across research blocks are further illustrated in **FIGURE 3**, which shows variations in light intensity.

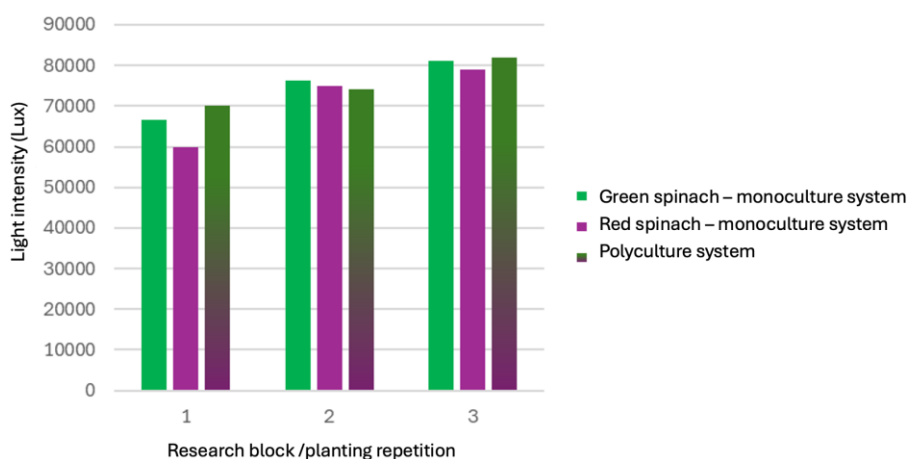


FIGURE 3. Variation in light intensity across treatments in each research block

FIGURE 3 shows variations in light intensity across all treatments within research blocks. Light intensity in block 1 tended to be lower than in blocks 2 and 3, with values ranging from approximately 60,000 to 82,000 lux. These differences were associated with varying levels of shading across blocks due to buildings and vegetation surrounding the planting area. Variations in light intensity among blocks were presumed to contribute to differences in plant growth responses and the high coefficient of variation values observed in several measured parameters.

TABLE 2. Leaf area ratio (cm²/g) of both green and red spinach after 35 days after sowing

Treatment	Leaf area ratio (cm ² /g)	
	35 DAS	
Planting system		
Sole cropping	13.43	a
Polyculture	14.19	a
Spinach cultivar		
Green spinach	13.07	p
Red spinach	14.55	p
Interaction	-	
CV (%)	13.37	

Values followed by the same letters within the same column indicate no significant difference based on Tukey's Honest Significant Difference (HSD) test at 95% confidence level. The symbol (-) indicates no interaction. DAS = days after sowing.

Based on **TABLE 2**, the leaf area ratio (LAR) value in the polyculture system tended to be higher than that in the sole cropping system. However, statistically the difference was not significant. This condition indicates that the distribution of biomass for leaf area formation was relatively similar across both cropping systems. The higher LAR value in the polyculture system indicates a tendency of plants to develop larger leaf areas per unit of plant dry weight. Differences in growth responses among research blocks were associated with naturally varying environmental conditions in the *pekarangan*, particularly shading levels caused by surrounding buildings and vegetation in the research area, which also been reported in wild plant population as in urban mangrove (Wibisono et al., 2024). According to Poorter et al. (2019), changes in environmental conditions such as light intensity can affect biomass allocation and vegetative plant growth. The CV value of 13.37% indicates moderate data variability, suggesting that plant responses among treatments were relatively stable.

Chlorophyll content measurements were conducted at 35 DAS because the leaves had fully developed and were more representative of the plants' photosynthetic capacity during the late vegetative stage. The observation results showed that chlorophyll content in both spinach cultivars, under both sole cropping and polyculture systems, did not differ significantly.

TABLE 3. Chlorophyll content (mg/L) at 35 DAS

Treatment	Chlorophyll content (mg/L)
Planting system	
Sole cropping	57.74 a
Polyculture	52.64 a
Spinach cultivar	
Green spinach	52.66 p
Red spinach	57.72 p
Interaction	-
CV (%)	12.5

Values followed by the same letters within the same column indicate no significant difference based on Tukey's Honest Significant Difference (HSD) test at 95% confidence level. The symbol (-) indicates no interaction. DAS = days after sowing.

Based on **TABLE 3**, total chlorophyll content in the sole cropping system (57.74 mg L⁻¹) and the polyculture system (52.64 mg L⁻¹) did not differ significantly. The total chlorophyll content of green spinach (52.66 mg L⁻¹) and red spinach (57.72 mg L⁻¹) also showed statistically similar results. The absence of interaction between cropping system and spinach type confirms that these two factors did not influence each other in determining total chlorophyll content. Chlorophyll content measurements were conducted at 35 DAS because the leaves had fully developed and were considered representative of the photosynthetic capacity of the plants during the final vegetative growth stage.

These results indicate that total chlorophyll content in spinach was not affected by differences in cropping systems or spinach cultivars at 35 DAS. This condition suggests that the growing environment among plots was still capable of supporting relatively balanced chlorophyll formation. Nevertheless, variations in light intensity among research blocks, as shown in **FIGURE 3**, were presumed to influence plant physiological responses, although the effect was not strong enough to produce statistically significant differences. Nájera et al. (2023) stated that differences in light intensity can affect physiological responses and photosynthetic efficiency in cultivation systems with heterogeneous environments. The presence of anthocyanin pigments in red spinach also did not cause significant differences in chlorophyll content because these pigments function in protecting photosynthetic tissues from excessive light radiation without inhibiting chlorophyll biosynthesis. According to Gould (2004), anthocyanins act as photoprotectors, helping reduce light stress in plant tissues. Therefore, the photosynthetic capacities of both spinach cultivars were relatively equivalent at this growth stage.

Several studies have reported that different cropping systems can regulate photosynthesis and plant physiological parameters by altering resource-use efficiency and antioxidant enzyme activity, thereby affecting plant growth and biomass accumulation (Ghani et al., 2023). However, in this study, these differences did not show statistically significant effects at 35 DAS. This condition was presumed to be influenced by the high microclimatic heterogeneity in *pekarangan*, particularly differences in light intensity and shading levels across research blocks, leading to more variable plant responses. The relatively high coefficient of variation (CV) value also indicates considerable environmental

variability, thereby reducing the sensitivity of statistical tests to treatment effects. In addition, variations in light intensity and limited growing space played a greater role in determining plant responses than the cropping system treatments or spinach cultivars.

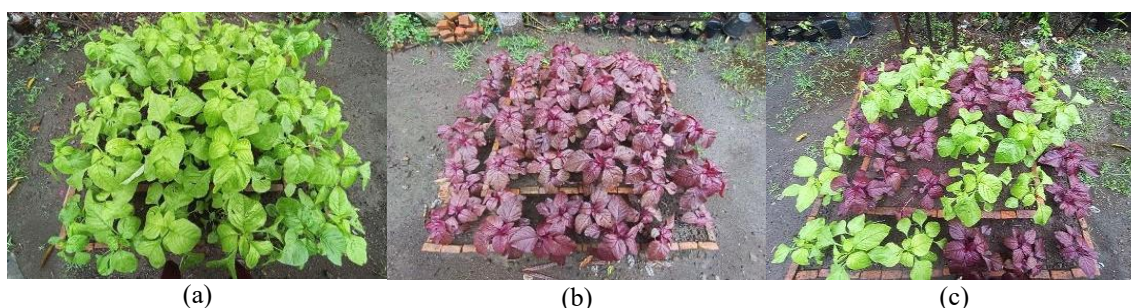


FIGURE 4. Growth condition of spinach plants at 35 DAS: (a) sole cropping of green spinach, (b) sole cropping of red spinach, and (c) polyculture system of green spinach and red spinach.

TABLE 4. Net assimilation rate ($\text{g}/\text{cm}^2/\text{day}$) at 35 DAS

Treatment	Net assimilation rate ($\text{g}/\text{cm}^2/\text{day}$)
	35 DAS
Planting system	
Sole cropping	0.018 a
Polyculture	0.015 a
Spinach cultivar	
Green spinach	0.018 p
Red spinach	0.016 p
Interaction	-
CV (%)	27.43

Values followed by the same letters within the same column indicate no significant difference based on Tukey's Honest Significant Difference (HSD) test at 95% confidence level. The symbol (-) indicates no interaction. DAS = days after sowing.

Based on **TABLE 4**, the Net Assimilation Rate (NAR) at 35 DAS did not differ significantly among either cropping systems or spinach types. The mean NAR of green spinach ($0.018 \text{ g}/\text{cm}^2/\text{day}$) and red spinach ($0.016 \text{ g}/\text{cm}^2/\text{day}$), as well as sole cropping ($0.018 \text{ g}/\text{cm}^2/\text{day}$) and polyculture ($0.015 \text{ g}/\text{cm}^2/\text{day}$), were followed by the same letters in the HSD test. The relatively high coefficient of variation value (27.43%) indicates variability in responses among replications. NAR measurements were conducted at 35 DAS because, at this stage, leaf area and plant biomass had developed optimally, thereby providing a more stable estimate of plant net assimilation efficiency than the early growth stage. Measurements at 14 and 21 DAS were not conducted because plant biomass accumulation and leaf area were still relatively low, so NAR could not yet optimally represent plant photosynthetic capacity.

The absence of significant differences indicates that the efficiency of biomass accumulation per unit leaf area was relatively similar across all treatments. This suggests that cropping systems and spinach cultivars did not differ in their effects on plant NAR under *pekarangan* conditions. Variations in environmental conditions among blocks, particularly light intensity and shading levels, were presumed to influence plant physiological responses. Variations in light intensity in each research block were previously presented in **FIGURE 3**. The high environmental variability likely made plant responses across treatments less uniform, resulting in differences in means that were not statistically significant.

TABLE 5. Relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) at 35 DAS

Treatment	Relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$)
	35 DAS
Planting system	
Sole cropping	0.32 a
Polyculture	0.28 a
Spinach cultivar	
Green spinach	0.31 p
Red spinach	0.29 p
Interaction	-
CV (%)	16.13

Values followed by the same letters within the same column indicate no significant difference based on Tukey's Honest Significant Difference (HSD) test at 95% confidence level. The symbol (-) indicates no interaction. DAS = days after sowing.

Based on TABLE 5, the relative growth rate (RGR) values in the sole cropping system ($0.32 \text{ g g}^{-1} \text{ day}^{-1}$) and the polyculture system ($0.28 \text{ g g}^{-1} \text{ day}^{-1}$) did not differ significantly according to Tukey's HSD test at a 95% confidence level. Similarly, among spinach types, green spinach ($0.31 \text{ g g}^{-1} \text{ day}^{-1}$) and red spinach ($0.29 \text{ g g}^{-1} \text{ day}^{-1}$) showed results that were statistically equivalent. No interaction between cropping system and spinach type was observed on RGR. The coefficient of variation (CV) of 16.13% indicates that data variability among replications remained moderate.

The relative growth rate (TABLE 5) did not show significant differences among cropping systems or spinach types. These results indicate that the rate of biomass accumulation was relatively uniform across all treatments, suggesting that differences in spinach type and cropping system had not yet exerted significant effects on relative growth rate during the observation phase. Gent (2017) demonstrated that RGR can be used to evaluate the growth efficiency of lettuce and spinach under different combinations of temperature and nutrient availability, where small differences in RGR are sufficient to distinguish adaptive plant responses to growing conditions. The slightly higher RGR value in green spinach indicates that biomass accumulation per unit of initial weight occurred more rapidly than in red spinach, consistent with the stronger vegetative growth vigour of the green cultivar.

TABLE 6. Productivity of both green and red spinach cultivars under planting systems ($\text{kg}/100 \text{ m}^2$)

Treatment	Productivity ($\text{kg}/100 \text{ m}^2$)
	35 DAS#
Planting system	
Sole cropping	134.0 a
Polyculture	73.1 a
Spinach cultivar	
Green spinach	126.9 p
Red spinach	80.2 p
Interaction	-
CV (%)	37.05

Values followed by the same letters within the same column indicate no significant difference based on Tukey's Honest Significant Difference (HSD) test at 95% confidence level. The symbol (-) indicates no interaction. The symbol (#) indicates that the data were transformed using \sqrt{x} (the square root of x) before analysis. DAS = days after sowing.

Based on TABLE 6, productivity in the sole cropping system ($134.0 \text{ kg}/100 \text{ m}^2$) tended to be higher than in the polyculture system ($73.1 \text{ kg}/100 \text{ m}^2$). However, the results of Tukey's HSD test showed that the two treatments were not significantly different at a

95% confidence level. Among spinach cultivars, the productivity of green spinach (126.9 kg/100 m²) was also higher than that of red spinach (80.2 kg/100 m²), but both showed statistically equivalent results. No interaction between cropping system and spinach cultivars was observed on plant productivity. The coefficient of variation (CV) of 37.05% indicates considerable variability across research replications.

Although the differences in mean productivity among treatments appeared relatively large, the statistical analysis showed that these differences were not significant. This condition was associated with a high coefficient of variation, indicating substantial environmental variability across research replications. High data variability reduced the sensitivity of statistical tests in detecting treatment effects, so differences in mean productivity could not yet be considered statistically significant. In addition, the limited number of replications affected the statistical analysis's ability to detect differences among treatments. According to Gomes (2000), high CV values in field experiments generally indicate environmental heterogeneity that can increase experimental error and reduce the precision of statistical testing.

The high variability among replications was associated with the microclimatic heterogeneity of urban *pekarangan*, particularly variations in light intensity and shading levels across research blocks. Variations in light intensity in each research block were previously presented in FIGURE 3. Differences in light interception can affect photosynthetic rate, biomass formation, and crop yield accumulation, thereby increasing variability in productivity responses across replications. Li et al. (2020) reported that light heterogeneity in mixed cropping systems can increase variability in plant growth and yield responses due to differences in resource competition. These conditions indicate that environmental factors likely played a more dominant role in affecting productivity than cropping system treatments or spinach cultivars.

Based on the Land Equivalent Ratio (LER) analysis, the polyculture system produced an LER value of 1.09. This value indicates that the polyculture system had 9% higher land-use efficiency compared with the sole cropping system. Thus, the polyculture system has the potential to be applied in *pekarangan* to improve land-use efficiency without reducing crop productivity. The LER represents the comparison of the land area required under a sole cropping system to produce an equivalent yield per unit area to that under a polyculture system (Mead & Willey, 1980). An LER value > 1 indicates that the polyculture system is more efficient in utilising growth resources than the sole cropping system.

An LER greater than one indicates that plant interactions in the polyculture system tended to be complementary rather than competitive. In this system, green spinach and red spinach were presumed to utilise growth resources differently, thereby reducing competition among plants. Differences in canopy characteristics, leaf colour, and physiological responses among spinach cultivars may allow more efficient light utilisation compared with the sole cropping system. Li et al. (2020) stated that mixed cropping systems can provide productivity advantages when complementary interactions among plants outweigh competitive effects. These conditions enabled the polyculture system to maintain land-use advantages even though the productivity of individual plants was lower than under sole cropping. The polyculture system shows the biodiversity in the cultivation of plants in *pekarangan*. Some researches show that biodiversity reflects the quality of ecosystems (Rahayu & Ervianti, 2020; Irwan et al., 2023; Koen et al., 2023).

Nevertheless, plant growth and productivity responses in this study were also influenced by the microclimatic heterogeneity of *pekarangan*. Variations in light intensity and shading levels among research blocks, as shown in FIGURE 3, were presumed to lead to more heterogeneous plant responses. This condition was reflected in high coefficient

of variation (CV) values for several parameters, particularly productivity, thereby reducing the sensitivity of statistical tests to treatment effects. Such microclimatic heterogeneity indicates that environmental factors exerted a relatively dominant influence on plant growth and yield compared with cropping system treatments. Nájera et al. (2023) reported that differences in light conditions in heterogeneous cultivation environments can affect plant physiological responses and productivity.

Relationships among parameters also indicated an association between physiological responses and plant productivity. Relatively higher chlorophyll content in several treatments was presumed to support increased plant photosynthetic capacity, thereby contributing to biomass formation and productivity. In addition, the tendency toward higher net assimilation rate (NAR) values suggests that increased efficiency in light capture and utilisation can support the accumulation of photosynthetic products. Therefore, plant productivity was influenced not only by cropping systems but also by interactions between plant physiological factors and the microclimatic conditions of the growing environment.

CONCLUSION

Monoculture and polyculture systems did not significantly affect the physiological parameters, growth, or productivity of spinach in urban *pekarangan*. Differences among cultivars only affected plant height during the early growth stage. Variations in light intensity across research blocks indicate microclimatic heterogeneity, which may have influenced plant responses. The polyculture system produced a Land Equivalent Ratio (LER) of 1.09, indicating higher land-use efficiency than the sole cropping system, thereby demonstrating its potential for application in *pekarangan* where space is limited in urban areas.

AUTHOR CONTRIBUTIONS

M.A.: conceptualisation, data collection, analysis, writing original draft; S.N.R.I.: supervision, methodology, review, editing; B.K.: supervision, methodology, review.

CONFLICTS OF INTEREST STATEMENT

There are no conflicts to declare.

ETHICAL COMPLIANCE

No ethical approval was required. The study involved plants (*Amaranthus tricolor* L.), which are not subject to ethical review.

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