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Research Article

Growth and water-needs analysis of sweet corn and peanuts in different cropping systems

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ABSTRACT

Maize and peanuts are important food crops in Indonesia and are generally planted in monoculture and intercropping systems. The water required for monoculture and intercropping is believed to be different. However, comparison analysis of water requirements in monoculture and intercropping is rarely conducted. The research aimed to evaluate the growth and production of sweet corn and peanuts in monoculture and intercropping systems concerning water requirement and crop coefficient. The study was conducted at IPB Experimental Station in Leuwikopo, Bogor, Indonesia from September to December 2022. Sweet corn and peanuts were planted in different cropping systems, i.e., monoculture and intercropping. Water consumption of both cropping systems was evaluated in every growing stage. The experiment used a completely randomized block design and was repeated three times. Results showed that sweet corn growth was not significantly different among cropping systems, but yield from intercropping was lower than monoculture. Intercropped peanuts grew lower than monoculture but did not show any significant difference in yield among cropping systems. Water use efficiency in intercropping was higher than monoculture for both crops, indicating intercropping is a suitable cropping system for limiting soil water availability. The land equivalency ratio was 1.80, concluding that intercropping was more efficient than monoculture in land use by 80%.

Keywords: climate change; crop coefficient; intercropping; land equivalent ratio; water use efficiency

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INTRODUCTION

Maize (*Zea mays* L.) and peanut (*Arachis hypogea* L.) are global essential commodities (Arya et al., 2016). In Indonesia, maize is predominantly grown for feeds, although some exotic varieties are used as exceptional cuisine in many regions (Syahruddin et al., 2020). Maize is also used in limited amounts as raw material for food, cosmetics, and oil industries in Indonesia (Nirmala et al., 2022). Peanuts or groundnuts are a cosmopolitan crop in Indonesia, and they are an essential ingredient in the food street and food industries (Hasanah et al., 2023). Therefore, both commodities contribute to Indonesia's food security (Syahruddin et al., 2020; Hasanah et al., 2023).

However, the production competitiveness of both maize and peanuts faces many challenges, mainly due to the increasing cost of production in small-land holders (Laoli et al., 2023) and climate change that affects water availability (Bharambe et al., 2023). The average land size by farmers in Indonesia is below 0.2 ha (BPS, 2018), and the low land size becomes a limiting factor for farmer income (Utami et al., 2016; Alfrida & Noor, 2017).

In such situations, the effort to increase farmer income could be by intercropping (Arsyad et al., 2020). The intercropping practice could reduce the risk of production failure (Herdiyanti et al., 2021).

Intercropping is a kind of cropping system that promotes the growing of two or more different crops on a single land at a similar particular time (Mousavi & Eskandari, 2011; Santosa et al., 2015). The system increases land use efficiency than monoculture by optimizing the use of light, water, and nutrients, controlling weeds, pests, and diseases, and improving soil fertility through N fixation from legumes (Lithourgidis et al., 2011), thus increasing plant productivity (Maure et al., 2019). Maize and peanuts are commonly grown as intercropping in Indonesia (Hulu & Setiawan, 2022). However, water analysis on monoculture and intercropping systems is rarely evaluated. According to Mogale et al. (2023), intercropping is a sustainable model against climate change. This research evaluated the growth and production of sweet corn and peanuts in monoculture and intercropping systems concerning water requirement and crop coefficient.

MATERIALS AND METHODS

Experimental site and design

The research was conducted from September to December 2022 at Leuwikopo Experimental Station of IPB University, Dramaga, Bogor. Post-harvest observations were conducted at the Postharvest Laboratory and Microtechnical Laboratory of the Department of Agronomy and Horticulture IPB University. The sweet corn used the Talenta variety, and the peanut used the Lurik variety.

The experiment used a single-factor, completely randomized design with the treatment of cropping systems. The cropping systems were sweet corn monoculture, peanut monoculture, and intercropping of sweet corn and peanut. Each treatment was repeated three times, resulting in nine combinations. Each combination used a 5 m x 5 m plot. A simple ombrometer was installed in the field to measure daily rainfall, and a simple pan was placed to measure surface evaporation.

Planting system

Planting was done using full-tillage. Tillage was carried out using a tractor, and the planting row was constructed manually. One week before planting, dolomite at a dose of 400 kg ha^{-1} and organic manure (cow manure) at 2 tons ha^{-1} were applied.

Monoculture peanuts used plant spacing of 20 cm x 20 cm, while intercropped peanuts used plant spacing of 80 cm x 20 cm. Monoculture and intercropped sweet corn used an 80 cm x 20 cm plant spacing. Fertilizer application was done by side-dressing using a single level for all cropping systems, i.e., urea 100 kg, SP-36 200 kg, and KCl 150 kg ha^{-1}. Fertilizers were applied twice where 1/3 of urea and all phosphorus and potassium were applied at planting, while the rest of the urea was added at four weeks after planting (WAP).

Plant maintenance, including weeding, was carried out weekly by uprooting the weeds. Pest and disease control was carried out monthly by applying insecticides such as carbofuran (Furadan 3G®) and fungicides such as Mancozeb 80% (Dithane-M45®). Water was applied through sprinkler irrigation in the absence of rain or soil humidity, based on the soil moisture meter, which shows below 70%. Sweet corn from monoculture and intercropping was harvested 75 days after planting (11 WAP), while peanuts were harvested 82 days after planting (12 WAP).

Observations

The growth and yield of sweet corn were observed, including plant height, stem diameter (10 cm from soil surface), leaf number, and canopy width. The leaf number was counted from the fully open ones. The canopy width was a projection of the outer leaf part. Yield of sweet corn was observed for dry weight of stover, corn weight with- and without cob, cob size (length and diameter), and harvest weight per plot (5 m x 5 m).

Vegetative observations on peanut growth included plant height, leaf number, branch number, and canopy width. The production included stover dry weight, pod number, pod weight, full and empty pod number, and pod weight per plot (5 m x 5 m).

Sweet corn and peanut growth were divided into four phases to calculate water requirements. The growth stages of sweet corn and peanut were divided according to Sirait et al. (2020), i.e., the first phase consisted of 20 days (initial phase), the second phase 25 days (crop development), the third phase 25 days (mid-season), and the fourth phase 10 days (late-season). For peanut, Sirait et al. (2020) divided the growth phase into the initial phase: 15 days, crop development 20 days, mid-season 35 days, and late-season 12 days.

Rainfall (P) was calculated using the following formula:

$$P = \frac{10 \text{ x V}}{\text{A}}$$

where P = rainfall height (mm), V = rainfall volume (mL), and A = rain gauge surface area (cm^2). The rain volume was collected using a hand-made rain gauge of PVC tube 4". It was installed in an open area close to experimental plots.

Soil evaporation (Eo) was calculated using the formula of Allen et al. (1998):

$$Eo = P - (H1-H0)$$

where Eo = surface evaporation (mm), P = rainfall height (mm), H1 = pan water height at the time of observation (mm), and H0 = maintained pan water height (mm). Soil evaporation was obtained from open space close to experimental plots.

The standard of evapotranspiration value (ETo) was calculated using the formula (Allen et al., 1998):

$$ETo = Eo \text{ x } Kp$$

where ETo = standard evapotranspiration (mm), Eo = surface evaporation (mm), and Kp = pan coefficient. The pan coefficient was set to 0.8, as adopted by Barung and Pattipeilohy (2020).

Actual evapotranspiration value (ETc) was calculated using the formula (Allen et al., 1998):

$$ETc = P + I - Pk \pm \Delta S$$

where ETc = evapotranspiration (mm), P = rainfall (mm), I = irrigation (mm), Pk = percolation (mm) and ΔS = changes in soil moisture content (% volume). The percolation value was set at 2 mm day^{-1}, according to Manihuruk & Setiawan (2022), considering the clay soil type in Dramaga, Bogor.

Crop coefficient (Kc) was calculated through the formula (Allen et al., 1998), where:

$$Kc = ETc/ETo$$

where Kc = crop coefficient, ETc = actual evapotranspiration (mm), and ETo = standard evapotranspiration (mm). Kc value was evaluated in each growth stage of both sweet corn and peanut.

Land equivalence ratio (LER) was calculated by referring to De Wit & Van (1965):

$$LER = (ya/Ya) + (yb/Yb)$$

where Ya = sweet corn crop production in monoculture system, ya = sweet corn crop production in intercropping system, Yb = peanut crop production in monoculture system, and yb = peanut crop production in intercropping system. LER larger than 1 indicated the benefit of the intercropping system (De Wit & Van, 1965).

The Water Use Efficiency (WUE) is determined using the formula developed by Franco et al. (2018). WUE is calculated as the dry yield per plant (kg $plant^{-1}$) divided by the total water input (kg $plant^{-1}$ mm^{-1}). The formula used for calculating is:

$$WUE = \frac{\text{Weigh of the harvested plant parts (kg)}}{\text{Rainfall+Irrigation (mm)}}.$$

Statistical analysis

Data obtained from observations were processed and analyzed using Minitab 18.0. Initially, data were analyzed using analysis of variance (ANOVA). Variables with significant effects of treatment after ANOVA analysis were then further analyzed using the Tukey (HSD) at the 5% level.

RESULTS AND DISCUSSION

Plant growth

Sweet corn growth in monoculture and intercropping systems showed no significant differences in plant height, canopy width, leaf number, and stem diameter (Figure 1). Those data indicated that sweet corn had less competition to peanuts in the intercropping system. From the perspective of canopy architecture, sweet corn, as shown in Figure 1A, had a taller canopy than peanut (Figure 1E). This means that sweet corn still receives full sunlight when intercropping with peanuts. This finding aligns with research conducted by Hulu and Setiawan (2022), where intercropping maize and peanut did not affect maize growth.

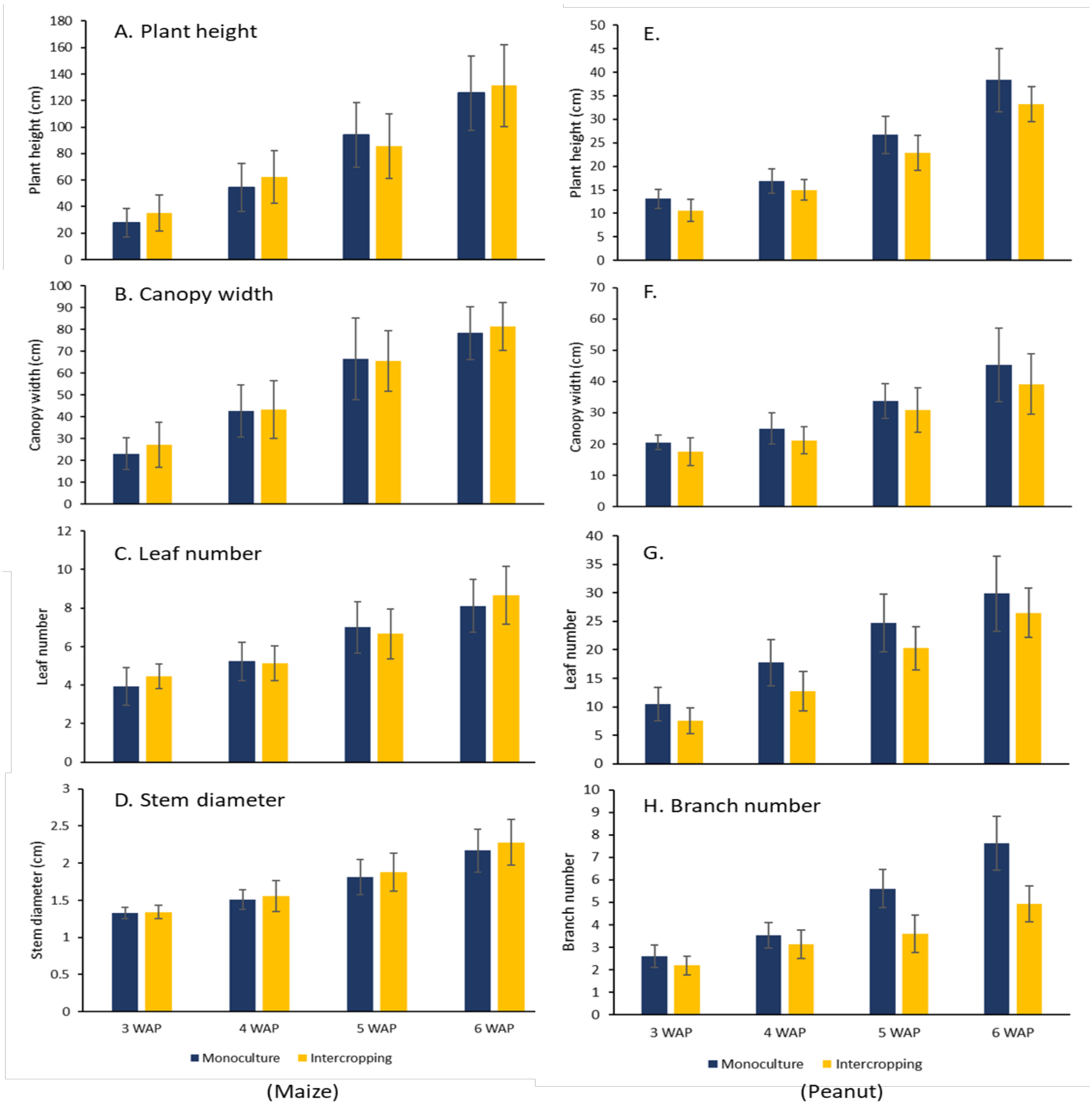

Figure 1. Plant height (A, E), canopy width (B, F), leaf number (C, G), stem diameter of sweet corn (D), and branch number of peanut (H) of both sweet corn (left) and peanut (right) grown in monoculture and intercropping systems. Numbers followed by similar letters in the same week are non significantly different based on the Tukey test α = 5%. Bar ± SE, n=10.

Cropping systems influenced peanut growth in all observed variables (Figure 1). Peanuts had taller canopies and had more branches in monoculture than in the intercropping system (Figure 1E and 1H). Figure 1G shows that monoculture stimulated peanuts to produce more leaves at 3-5 WAP than in the intercropping and to create a more expansive canopy at 3 WAP and 4 WAP. Nevertheless, canopy width at 5 WAP and 6 WAP was insignificant among cropping systems (Figure 1F).

Figure 1E-G concludes that peanut growth was more favorable in monoculture than intercropping. The conclusion is in line with Fadhillah et al. (2018), who reported that the development of peanut plants in intercropping was significantly lower than in monoculture. Peanut canopy in intercropping likely received less sunlight than monoculture. In intercropping, the sweet corn canopy covered around 80 cm in diameter (Figure 1B) at 6 WAP, which means that space between sweet corn rows, including the peanut canopy, was covered by the canopy of sweet corn (Figure 2). Unfortunately, light intensity was not measured in the present experiment. Lower growth of peanuts under canopy in the present experiment due to reduction of light intensity is hypothesized from the report of Noertjahyani et al. (2020), who stated that peanuts grown under shade treatment significantly reduced the number of branches and leaves.

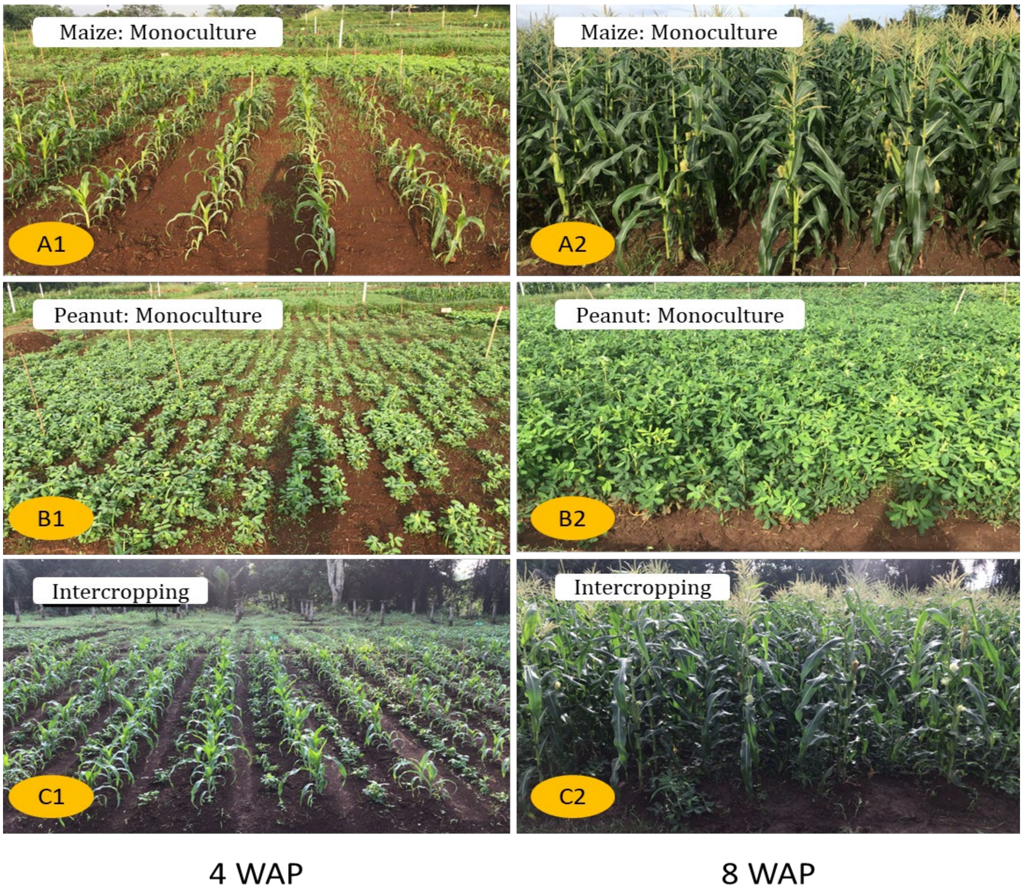

Figure 2. Field situation of sweet corn and peanut grown in monoculture (A-B) and intercropping systems (C). The left side is four weeks after planting (WAP), and the right side is eight weeks old.

Biomass and grain production

Peanut biomass, including stem and leaves, was significantly lower in intercrop than in monoculture (Table 1). A similar tendency occurred for sweet corn, where plants under intercropping had lower leaves and stem dry weight, although it was statistically identical at α 5%. Interestingly, the root dry weight in monoculture sweet corn was significantly higher than intercropping. However, the root-to-shoot ratio (R-S) tended to be high in intercropping for both sweet corn and peanuts (Table 1). The increasing R-S ratio in sweet corn was about 11.6%, while in peanuts, it was 11.0% from monoculture to intercropping. According to Esnarriaga et al. (2020), intercropping increases the root-shoot ratio, especially for beans, due to the favorable rooting system.

Although total biomass per plant in intercropping was lower than in monoculture, in the present experiment, plants likely allocated more assimilated roots than shoots in the intercropping system. The decrease in the weight of sweet corn and peanut biomass in intercropping can also be caused by underground competition for water absorption and nutrients. Further study is needed to evaluate the factors determining the underground intercropping competition.

Table 1. Dry weight of sweet corn and peanut biomass grown in different cropping systems.

Cropping system	Sweet corn dry weight (g)				Peanut dry weight (g)			
	Root	Stem	Leaf	R-S ratio	Root	Stem	Leaf	R-S ratio
Monoculture	14.42a	136.60	47.45	0.078	8.91	16.32a	28.35a	0.199
Intercropping	12.38b	105.10	36.49	0.087	8.06	13.15b	23.26b	0.221
P-value	0.028	0.153	0.115	-	0.133	0.012	0.045	-

Note: Numbers followed by the different letters in the same column are significantly different based on Tukey test α = 5%; R-S: root to shoot ratio based on dry basis, shoot composed of stem plus leaf dry weight.

The dry weight of peanut stems and leaves in intercropping was significantly lower than in monoculture (Table 1). The substantially lower branching of peanuts in intercropping (Figure 1H) will reduce the dry weight of peanut stalks. Saragih et al. (2019) reported that the growth and weight of peanut upper-ground biomass in intercropping systems are lower than in monoculture.

Cob size and yield of sweet corn were significantly higher in monoculture than in intercropping in the similar population, but no significant difference was apparent for cob diameter (Table 2). The cob length was proportional to the cob weight, and the plot harvest produced in monoculture was higher than intercropping. These results were similar to the finding of Sembiring et al. (2015) that maize intercropped has a lower yield. On the other hand, the yield component of peanuts was statistically similar between monoculture and intercropping.

Table 2. Yield components of sweet corn and peanut grown in different cropping systems.

Yield components	Monoculture	Intercropping	P-value
		Sweet corn	
Cob length (cm)	20.92a	20.18b	0.022
Cob diameter (cm)	3.93	3.71	0.116
Cob weight with sheath (g)	384.40a	330.10b	0.002
Cob weight without sheath (g)	264.00a	226.91b	0.019
Fresh cob yield per plot (kg)	19.20a	16.43b	0.015
Yield per hectare (ton)	7.68a	6.57b	0.015
		Peanut	
Pod number per plant	8.30	11.00	0.064
Pod weight per plant (g)	31.69	26.00	0.208
Filled pods per plant	6.50	8.00	0.148
Empty pods per plant	1.70	2.90	0.237
Dry pod yield per plot (kg)	4.96	4.63	0.596
Yield per hectare (ton)	1.98	1.85	0.596

Note: Numbers followed by the different letters in the same row are significantly different based on Tukey test α = 5%.

The decrease in the stalk weight of peanuts in intercropping, as shown in Table 1, did not affect the number of pods and pod weight, as shown in Table 2. It is speculated that the peanut variety used in the present experiment could be adaptive for growing under intercropping. Lurik is a local variety that originated in East Nusa Tenggara, and still lacks of variety description. Nevertheless, Wicaksana (2023) reported that Lurik variety is adaptive to dryland conditions and resistant to bacterial wilt. Wangiyana et al. (2021) stated that peanut varieties exhibit different abilities to grow under shading. Still, further study is needed to evaluate the Lurik variety used in the present experiment and its shading levels.

In the present experiment, monoculture of sweet corn produced fresh yield cob 7.68 ton ha^{-1} while it was 6.57 ton ha^{-1} in intercropping (Table 2). From a farmer's perspective, 1.11 ton ha^{-1} of yield differences between monoculture and intercropping could be a significant amount of income. It seems that sweet corn had no benefit from peanut intercropping. On the other hand, the yield reduction in peanuts was 0.13 ton ha^{-1}. In the future, it will be interesting to evaluate the economic value of intercropping, especially for small-scale farmers, who are predominant in Indonesia.

Table 3. Irrigation, precipitation, standard evapotranspiration, actual evapotranspiration, and crop coefficient of sweet corn and peanut in different cropping systems.

Cropping	Growth phase (days)^{z}	I (mm)	P (mm)	ET_o (mm)	ET_c (mm)	K_c
			Sweet corn			
Mono-culture	I (20 days)	337.68	339.04	63.44	636.73	0.50
	CD (25 days)	168.84	441.94	28.00	560.78	0.80
	MS (25 days)	0	315.60	33.04	265.61	0.32
	LS (10 days)	0	152.64	36.16	132.64	0.37
	Total (75 days)	506.52	1249.22	160.64	1595.76	-
Inter-cropping	I (20 days)	320.46	339.04	63.44	619.51	0.49
	CD (25 days)	240.34	441.94	28.00	632.28	0.90
	MS (25 days)	0	315.60	33.04	265.61	0.32
	LS (10 days)	0	152.64	36.16	132.64	0.37
	Total (75 days)	560.8	1249.22	160.64	1650.04	-
			Peanut			
Mono-culture	I (15 days)	337.68	218.14	51.84	525.82	0.68
	CD (20 days)	168.84	294.74	16.64	423.58	1.27
	MS (35 days)	0	565.48	92.88	495.48	0.15
	LS (12 days)	0	170.88	18.96	146.88	0.65
	Total (82 days)	506.52	1249.24	180.32	1591.76	-
Inter-cropping	I (15 days)	320.46	218.14	51.84	508.60	0.65
	CD (20 days)	240.34	294.74	16.64	495.08	1.49
	MS (35 days)	0	565.48	92.88	495.48	0.15
	LS (12 days)	0	170.88	18.96	146.88	0.65
	Total (82 days)	560.8	1249.24	180.32	1646.04	-

Note: ^{z}Classification of Sirait et al. (2020), I-initial, CD-crop development, MS-mid-season, LS-late-season; I = irrigation, P = rainfall, ET_o = standard evapotranspiration, K_c = plant coefficient, ET_c = evapotranspiration.

Water balance

In sweet corn and peanut, the standard evaporation value was determined by crop, not by cropping system (Table 3). Water for growing sweet corn and peanuts mainly comes from rainfall (P), and supplement irrigation was applied mostly during the initial and crop development stages due to the scarcity of rainfall. The application of irrigation was considered based on soil moisture conditions below 70%.

The irrigation was applied through sprinklers, with about 10 mm of water in each application. During the experiment, monoculture received six times of irrigation, while intercropping received seven times of irrigation at crop development stages. Such differences were due to intercropping, which exhibited rapid drying in soil moisture compared to monoculture. The cause of the rapid soil moisture loss is still unclear in intercropping. Dense cropping probably stimulated high actual evapotranspiration (ETc), as shown in Table 3.

Table 3 shows that evapotranspiration rates vary by phase and cropping system in both sweet corn and peanut. Differences in evapotranspiration rate can vary due to climatic conditions, vegetation, and soil (Kool et al., 2014). Evapotranspiration rates in the initial phase tend to be high irrespective of crop and cropping system (Table 3). In the initial phase, high evaporation is due to limited vegetation cover (Sarminah et al., 2019).

In sweet corn and peanuts, irrespective of the cropping system, a high crop coefficient was apparent in the crop development phases, followed by the initial phase (Table 3). However, the crop coefficient in intercropping of both sweet corn and peanut tended to be higher than that of monoculture. Sandhu and Irmak (2019) stated that the crop coefficient tends to be small at the beginning of plant growth, gradually increases in the middle of the growth, and decreases at the end of growth.

Irrespective of the cropping system, the crop coefficient was determined by crop where peanuts had a higher value than sweet corn (Table 3). A crop with a lower coefficient means more water requirement efficiency. C4 plants like sweet corn are commonly understood to be more efficient in water requirement than C3 plants like peanuts (Hamim, 2005; Opoku et al., 2024). The difference in evapotranspiration will affect the value of the crop coefficient. The coefficient of intercropped peanuts in the crop development phase was higher than that of monoculture. In contrast to sweet corn, the peanut coefficient in this study decreased in the mid-season phase and then increased again in the late-season phase. The crop coefficient in both treatments was the same in the mid-season and late-season phases.

Water use efficiency

The study showed intercropping sweet corn+peanut had higher water use efficiency (WUE) than monoculture for both crops (Table 4). WUE shows the weight of harvested plant parts for every millimeter of water applied. The higher WUE in the intercropping system indicates more efficiency in water productivity. A similar study has also been reported by Ren et al. (2017), which states that intercropping increases yield per area without increasing water application, resulting in more efficient water use.

Table 4. Water use efficiency and land equivalent ratio of sweet corn and peanut from different cropping systems.

Treatment	Yield per plot (kg)[z]	Water input (mm)[y]	WUE (kg mm^{-1})	LER
Sweet corn: monoculture	19.20	585.25	0.033a	
Sweet corn: intercropped[x]	16.43	603.35	0.027b	
Peanut: monoculture	4.96	585.25	0.008c	
Peanut: intercropped[x]	4.63	603.35	0.008c	
Intercropping (sweet corn +peanut)	21.06	603.35	0.036a	1.80

Note: [z]Plot sized 5 m x 5 m; [y]Water input from irrigation and precipitation; [x]If each crop was calculated separately; WUE = water use efficiency; LER = land equivalent ratio. Numbers followed by the different letters in the same column are significantly different based on the Tukey test α = 5%.

Table 4 shows that if intercrop plants of sweet corn and peanut were calculated separately, individual WUE in intercropping was lower than in monoculture, especially for sweet corn. Here, sweet corn had 0.027 kg mm^{-1}, and peanut had 0.008 kg mm^{-1}, meaning that the efficiency of the peanut was similar in both monoculture and intercropping. Interestingly, sweet corn exhibited plasticity of WUE character in the intercropping system. Hidayatullah et al. (2020) have studied the presence of phenotypic plasticity of *Colocasia esculenta* in different water regimes. Kusmec et al. (2018) have pointed out the importance of finding phenotypic plasticity in maize as an essential component to adapt to unfavorable environments, including climate change. The present experiment revealed the phenotypic plasticity of WUE in sweet corn due to intercropping application.

The high value of WUE in intercropping systems indicated the benefit of intercropping for both sweet corn and peanut, as reflected by the high total yield per plot (Table 4). Unfortunately, yield quality of both sweet corn and peanut was not evaluated in the present study. The finding in the present research contrasts Franco et al. (2018), where peanuts intercropped with annual crops increased the WUE compared to monoculture. As shown in Table 4, the WUE of peanut was similar between monoculture and intercropping, i.e., 0.008 kg mm^{-1}.

Land equivalent ratio

The land efficiency ratio (LER) in intercropping was 1.8 (Table 4), indicating an increase of 80% in land productivity as compared to monoculture. This means that intercropped land was 80% more efficient than the monoculture of each sweet corn and peanut. The LER value was higher than reported by Sasmita et al. (2014), where intercropping maize and peanut gain 71% more efficiency in land use than monoculture.

The high LER of intercropping of maize with beans is common. Edy et al. (2020) pointed out that maize intercropped with mungbean increases LER due to the presence of root nodulation in mungbean. Prathyusha et al. (2022) state that peanuts can form root nodulations with bacteria to enhance nitrogen fixation and absorption. The yield stability of peanuts grown in intercropping in the present experiment was probably due to the presence of bacterial nodulation. However, bacterial nodulation was not observed in the present experiment.

The present study shows that the cropping system affects WUE, where intercropping is considered more efficient in water use than monoculture, especially the intercropping of sweet corn and peanuts. It is important to note that a combination of crops in intercropping could affect the WUE value because WUE is sensitive to species (Huang et al., 2023), growth stage (Budiarto et al., 2022), planting pattern (Ren et al., 2017), and ecology (Liu et al., 2017).

In crop selection, Rochmah et al. (2020) suggested to chose species with low crop competition. Selecting species with a low crop coefficient (Kc) is recommended here. Moreover, Opoku et al. (2024) noted that C4 crops (e.g., maize) are preferable in areas with elevated CO_2 concentration, high temperature, and sufficient water. In the present experiment, when monoculture is an option, it is recommended to plant sweet corn rather than peanuts due to higher WUE (Table 4).

CONCLUSIONS

Cropping systems affected WUE and crop coefficient (Kc). Peanuts exhibited higher Kc in monoculture and intercropping than sweet corn, and intercropping increased WUE. Intercropping sweet corn and peanuts increased the land equivalent ratio (LER) by 80%, which is more efficient than the monoculture system.

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