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Original Article

Sustainable management of food crop systems and cropping patterns on volcanic and sedimentary drylands for enhanced productivity and farmer prosperity

Popi Rejekiningrum[1], Zainal Arifin[2]*, Evy Latifah[2], Amik Krismawati[2], Sri Satya Antarlina[3], Moh. Saeri[4], Baswarsiati[2], Chendy Tafakresnanto[5], Dwi Setyorini[6], Annisa Dhienar Alifia[2]

[1]Research Center for Limnology and Water Resources, National Research and Innovation Agency, Cibinong, West Java 16911, Indonesia
[2]Research Center for Horticulture, National Research and Innovation Agency, Cibinong, West Java 16911, Indonesia
[3]Research Centre for Food Technology and Processing, National Research and Innovation Agency, Playen, Gunung Kidul, Yogyakarta 55861, Indonesia
[4]Research Centre for Behavioural and Circular Economy, National Research and Innovation Agency, Jakarta 12710, Indonesia
[5]Research Center for Food Crops, National Research and Innovation Agency, Cibinong, West Java 16911, Indonesia
[6]Research Center for Estate Crops, National Research and Innovation Agency, Cibinong, West Java 16911, Indonesia

**Corresponding author's email:* zain013@brin.go.id
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Abstract

A growing portion of Indonesia's dryland is dependent on agriculture, which necessitates adaptive technologies to assure year-round productivity and increase farmer income. This study created technological packages for food crops grown in a single-cropping system during the dry season in arid climate drylands. The methods were evaluated on one-hectare plots of volcanic soil (Situbondo) and sediment soil (Sumenep) with rice, corn, and soybeans. The rice-corn//corn system on volcanic soil produced the highest rice equivalent yield (18.1 t ha−1; CII 0.82; CI 285), followed by the corn-soybean-corn system on sediment soil (14.6 t ha−1; CII 0.80; CI 300). The LERs were 1.44 for corn double row relay planting with soybean (volcanic soil) and 1.52 for corn + soybean in sediment soil. Rice double row on volcanic soil yielded the highest profit (8.6 t ha−1; IDR 24.73 million; R/C 3.20), followed by corn double row on sediment soil (5.5 t ha−1; IDR 8.53 million; R/C 1.78).

Keywords: Cropping systems and patterns, Rice, Corn, Soybean, Yield, Dryland, Volcanic soil, Sediment soil

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Introduction

Drylands pose a significant challenge for meeting Indonesia's future food demands, as their potential remains underutilized primarily due to water limitations. A study estimated that with appropriate management reforms, drylands could produce up to ±11.34 million tonnes of upland rice and 6.91 million tonnes of beans annually. Indonesia has 13.3 million ha of dryland, currently contributing about 11.34 million tonnes of food crops, but with relatively low productivity (±1.17 t ha^{-1}). At present, drylands account for only 1.79% of national food production. Therefore, reforms combined with innovations in rainwater harvesting and integrated farming system technologies present substantial opportunities to enhance dryland productivity and support sustainable food security (Idjudin and Marwanto, 2008).

However, utilization and development of dryland agriculture have produced unsatisfactory results due over the years due to various challenges, including land biophysics, economic, socio-cultural, and institutions constraints (Suwardji, 2005). Most of the dryland areas consist of critical land characterized by small landholding, limited water availability, low soil fertility, shallow soil layer, and high susceptibility to erosion (Syafrudin and Saidah, 2006; Yofa et al., 2020; Zhao et al., 2024). Water resources are scarce and rely almost entirely on rainfall. Meanwhile, water supply can directly affect the grain yield of some plant species (Houshmandfar et al., 2019). Disparities in crop productivity across regions are largely attributed to variations in soil fertility, water availability, agroecological conditions, and the inaccuracy of cultivation practices. Dryland areas receive less than 2,000 mm rainfall per year with only 3-4 wet months (Mulyani and Sarwani, 2013), According to Dariah and Las (2010), the productivity of dry land remains relatively low and has not been managed optimally.

To address these challenges, appropriate technologies are required. The key points include using early-maturing and drought-tolerant varieties, combining tillage with suitable planting techniques, implementing balanced fertilization with organic matter, and managing water efficiently within an integrated cropping pattern. Therefore, crop management must be designed around a unified cropping pattern that accounts for existing rainfall opportunities.

Dryland has the potential to produce sufficient and varied food if managed with the right technology and development strategy. Various studies have reported that intensifying cropping patterns through crop diversification can yield more harvests per unit area and time (Halvorson et al., 2002; Kremen and Miles, 2012; Wunsch et al., 2017; Williams et al., 2023). The sustainability of irrigation systems can be strengthened through optimal cropping patterns, which are contingent upon efficient water management in agriculture (Fasakhodi et al., 2010). Dryland cropping patterns developed on dryland should minimize the interval between harvest and subsequent planting as much as possible to increase cropping intensity. Fasakhodi et al. (2010) and Sun et al. (2015) have highlighted that applying the correct planting schedule and pattern based on water balance analysis is critical. This approach helps plants avoid water shortage risk and can significantly increase farmers' income. The selection of site-specific planting technologies (such as drought adaptive and tolerant varieties, early maturing varieties with high yield potential, and optimized plant population management) can increase both land and crop productivity. A range of dryland technologies for food crop cultivation are available, including methods to increase soil fertility, management of soil organic matter, and water management. However, technologies must be aligned with local land characteristics and farmer conditions to ensure effectiveness and adoptability (Abdurrachman et al., 2008).

Intercropping, the practice of simultaneously growing diverse crops on the same field at the same time, is a sustainable intensification strategy offering the advantages of higher yields and increased profits (Li et al., 2020). Anchal and Sharma (2025) and Maitra et al. (2021) add that this involves planting two or more crops simultaneously to capitalise on their beneficial interactions. This system is deemed as alternative approach for agricultural intensification that is suited to raise agricultural output in less productive areas with low soil fertility and limited agricultural resources (Chen et al., 2025). Furthermore, intercropping can enhance land-use efficiency, minimize the risk of yield failure, and increase farmer's income (Rusinamhodzi et al., 2012; Ginting et al., 2023).

Relay intercropping is a technique in which a second crop is planted among a standing crop during the latter's reproductive stage, but before harvest. The seedling rate of each crop is lowered below its maximum rate in the combination to increase plant

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density and avoid competition related to overpopulation (Maitra and Gitari, 2020).
Intercropping on dryland helps maintain soil moisture and water content, reduce erosion, and increase soil fertility (Rosenzweig et al., 2018; Ma et al., 2024). Moreover, Lithourgidis et al. (2011) adds that intercropping optimizes the use of light, water and nutrients, while helping to control weeds, pests and diseases, and also improve soil fertility through N fixation from legume plants. Severe water shortages due agricultural land expansion and rising water demands threaten the sustainability of agriculture (He et al., 2020; Zhang et al., 2021; Fan et al., 2022). According to Machado et al. (2008), increasing the productivity of dryland under limited water availability requires implementing cropping system that enhance water reserves, improve water use efficiency (WUE), and reduce erosion. One such approach is intercropping upland rice with adjusted planting density to optimize yields (Rasool et al., 2012). Shading from denser populations lowered light intensity, disrupting photosynthesis and carbohydrate synthesis, and ultimately reducing plant growth and productivity (Dewi et al., 2014; Postma et al., 2021). Shade affects the processes of photosynthesis, respiration, transpiration, nitrate reduction, protein synthesis, hormone production, translocation and aging (Struik and Deinum, 1982).
Furthermore, intercropping systems require optimal spacing (population) to minimize competition for light, nutrients, and water, which otherwise reduce plant yields (Prasad and Brook, 2005; Muoneke et al., 2008; Syafruddin, 2016). Double row cropping system is a technique to control plant density and increase the plant population per unit area (Erythrina and Zaini, 2014). Aside from spacing, rice productivity can also be increased by using seeds from high-yielding, new superior varieties (Husnain et al., 2016).
This research was aimed to develop an integrated cropping technology package for food crops to increase dryland productivity and income of farmers.

Material and Methods

Research activities on food crop patterns on dryland with dry climates in a 10,000 m^2 area in the volcanic soil of Jatisari village, Arjasa district, Situbondo Regency and sediment soil of Manding Timur village, Manding district, Sumenep Regencies, East Java Province, Indonesia. Management of food crops in a single-cropping pattern includes rice, corn and soybeans planted in monoculture or intercropping (+), and relay planting (//) of corn or soybeans. The plant spacing are as follows; rice: 20 cm × 20 cm, rice double row: 40 cm × 20 cm × 10 cm, corn: 75 cm × 20 cm, double row corn: 100 cm × 50 cm × 20 cm, intercropped corn: 160 cm × 40 cm, soybeans: 40 cm × 15 cm. Type and dosage of fertilization for rice (main crop) are: Urea 200 kg ha^{-1} + SP 36 100 kg ha^{-1} + KCl 50 kg ha^{-1} + Organic fertilizer 2000 kg ha^{-1}. For corn (main crop): Urea 300 kg ha^{-1} + SP 36 100 kg ha^{-1} + 50 kg ha^{-1} KCl + 1000 kg ha^{-1} organic fertilizer. Finally, for soybeans (main crop): SP 36 75 kg ha^{-1} + 50 kg ha^{-1} KCl + 1000 kg ha^{-1} organic fertilizer.
The study of rice, corn, and soybean planting systems and patterns was arranged randomly in groups of 7 treatments repeated 4 times, namely: A. Rice – Rice; B. Rice - Rice double row; C. Rice – Rice double row / Corn, D. Rice - Corn // Corn, E Rice – Corn double row // Soybean, F. Rice – Soybean + Corn, and G. Rice – Soybean – Corn, as listed in Table 1.

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Table-1. Management of cropping system for food crops in dry land with dry climates, volcanic soil in Situbondo and sediment soil in Sumenep.

Treatment	Monoculture and Intercropping System				
	First planting		**Second planting**		**Third planting**
A	Rice (var. Ciherang)	–	Rice (var. Inpago 1)		
B	Rice (var. Ciherang)	–	Rice double row (var. Inpago 1)		
C	Rice (var. Ciherang)	–	Rice double row (var. Inpago 1)	ǂ	Corn (var. HJ 21)
D	Rice (var. Ciherang)	–	Corn (var. HJ 21)	//	Corn (var. HJ 21)
E	Rice (var. Ciherang)	–	Corn double row (var. HJ 21)	//	Soybean (var. Dering 1)
F	Rice (var. Ciherang)	–	Soybean (var. Dering 1)	ǂ	Corn (var. HJ 21)
G	Rice (var. Ciherang)	–	Soybean (var. Dering 1)	-	Corn (var. HJ 21)

The observations included: (1) pre-study soil analysis to determine the nutrient status of the soil in relation to crop growth and yield; (2) rainfall, including distribution and intensity, as a factor in determining cropping systems and patterns; (3) rice, corn and soybean yields (t ha^{-1}) results from the implementation of cropping systems and patterns; (4) Land Equivalent Ratio (LER), (5) Cropping Intensity Index (CII), and (6) farming analysis of monoculture and intercropping rice, corn and soybean in the second planting time (dry season) with the R/C ratio.

LER is the relative land area of intercropping to obtain yields compared to monoculture plantings. The calculation of LER (Mead and Willey, 1980) can be seen in Equation 1 as follows:

$$\mathbf{LER} = \sum_{\mathbf{i=1}}^{\mathbf{m}} \frac{\mathbf{Yij}}{\mathbf{Yii}} \qquad \textbf{(1)}$$

Where:

Yij = Yield of the i-th component under intercropping conditions

Yii = Yield of these components under monoculture cropping conditions in intercropping areas

The LER value is interpreted as follows,

LER = 1 : The yield of the intercropping cropping is the same as the result of each of the two plantations in the same area as the intercropping area

LER >1 : The yield from intercropping is higher (profitable) than each of the two plantations in the same area as the intercropping area

LER <1 : The yield from intercropping is lower (not profitable) from each of the two plantations in the same area as the intercropping area

The land-use efficiency of the evaluated cropping patterns was quantified using the Cropping Intensity Index (CII) adapted from Menegay et al. (1978). Since all crops within each treatment were cultivated sequentially on the same base field (A_0) without any temporarily added or rented land (M = 0), the index was calculated using the simplified formula in Equation (2):

$$\mathbf{CII} = \frac{\sum_{i=1}^{N_C} a_i\, t_i}{A_0 T} \qquad \textbf{(2)}$$

Where:

i = 1, 2, 3, …. N_c

N_C = number of plantings during period T

a_i = area covered by the i-th cropping

t_i = duration of the i-th crop (days)

T = study time period (365 days)

A_O = total cultivated land available during period T (1.0 ha).
And the Cropping Intensity (CI) was estimated using the formula below (Equation 3) (Faruque et al., 2017).

$$\textbf{Cropping Intensity} = \frac{\text{total cropped area (ha)}}{\text{net sown area (ha)}} \times \mathbf{100} \qquad \textbf{(3)}$$

The cropping system's productivity was assessed using the Rice Equivalent Yield (REY) parameter, which is calculated using quation 4 below:

$$\textbf{REY} = \frac{\textbf{Yield of crop x Price of crop}}{\textbf{Price of rice}} \qquad \textbf{(4)}$$

Notes: REY = Rice Equivalent Yield; Yield of crop (kg ha-1); Price of crop (IDR kg-1); Price of rice (IDR kg-1).
The feasibility of monoculture crop farming and intercropping of rice, corn and soybeans are analyzed by calculating the R/C ratio (Soekartawi, 1995) using Equation 5:

$$\textbf{R/C ratio} = \textbf{TPV/TCV} \qquad \textbf{(5)}$$

Where:
R/C = Revenue and cost ratio
TPV = Total production value (IDR/ha)
TCV = Total cost value (IDR/ha)
The result of R/C ratio is interpreted as follows,
R/C > 1 : Feasible to develop
R/C = 1 : Break even
R/C < 1 : Not feasible to develop
An analysis of variance (ANOVA) was conducted to evaluate the impact of cropping systems and cropping patterns on crop yield parameters. Following the ANOVA analysis, Duncan's Multiple Range Test (DMRT) at a 5% significance level was performed to determine which treatments yielded significantly different results.

Results

Characteristics of research locations

The soil physicochemical characteristics of both locations revealed distinct patterns related to their parent material. The first location in Situbondo Regency are old volcanic soils with a very shallow soil depth (solum) of around 5.5 cm-9.5 cm, while locations in Sumenep Regency are sediment soils with a very shallow soil depth (solum). about 12 cm-15 cm. (Table 2). .

Table-2. Results of analysis of soil nutrients before research activities on cropping systems and patterns on dry land volcanic soil (Situbondo) and sediment soil (Sumenep).

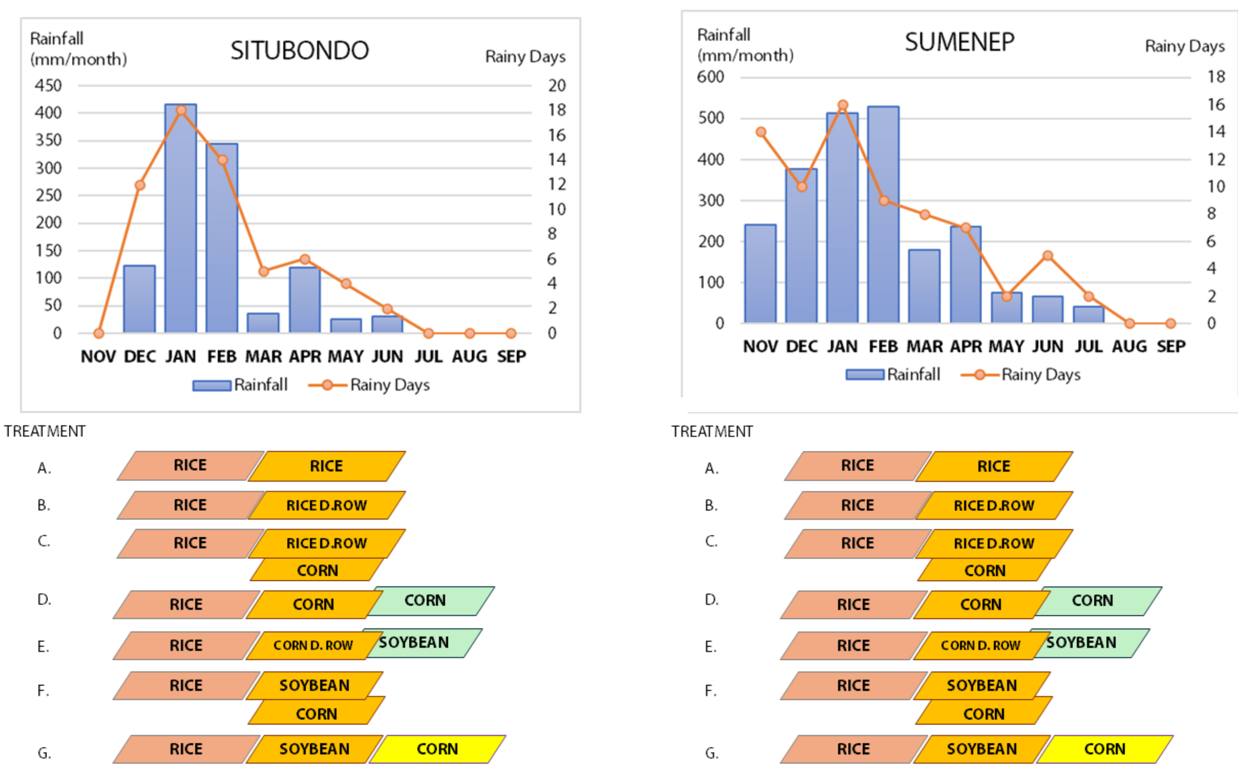
Parameters	Volcanic soil		Sediment soil	
	Value	Criteria	Value	Criteria
- Water content	2.43%	-	1.91%	-
- pH H_2O	7.06	Neutral	8.61	Alkaline
- pH KCl	5.27	-	7.56	-
- C-organic	0.76%	Very low	0.99%	Very low
- N-total	0.19%	Low	0.25%	Moderate
- P_2O_5 available	57.43 ppm	Low	66.29 ppm	Low
- Exchangeable K	0.43 me.100 g^{-1}	Moderate	0.22 me.100 g^{-1}	Low
- Exchangeable Ca	7.62 me.100 g^{-1}	Moderate	23.77 me.100 g^{-1}	Very high
- Exchangeable Mg	1.36 me.100 g^{-1}	Moderate	0.45 me.100 g^{-1}	Low
- Exchangeable Na	0.30 me.100 g^{-1}	Low	0.12 me.100 g^{-1}	Low
- CEC	16.38 me.100 g^{-1}	Low	15.17 me.100 g^{-1}	Low
- Sand	63%		43%	
- Dust	17%	Sandy clay loam	30%	Loam
- Clay	21%		27%	

Source: Results of soil analysis at East Java AIAT's laboratory of soil, plant, fertilizer, water.

The sediment soil was alkaline (pH 8.61), while the volcanic soil was neutral (pH 7.06). Soil pH is one of the most important chemical properties that affect agricultural productivity and ecosystem function (Havlin et al., 2017; Weil and Brady, 2017). Soils with alkaline pH are typically found in dry areas with limited rainfall, which restrict the process of leaching (Qadir and Schubert, 2002). The relationship between soil pH and nutrient availability is complex and varies significantly depending on the nutrients in question (Fageria and Baligar, 2005). Organic carbon content was very low on both soil types, valuing at 0.76% in volcanic soil and 0.99% in sediment soil. Total nitrogen levels differed slightly, with volcanic soil categorized as low (0.19%) and sediment soil as moderate (0.25%). The available P_2O_5 content was low in both soils, at 57.43 ppm for volcanic and 66.29 ppm for sediment soil.

Exchangeable Ca was notably higher in sediment soil (23.77 me 100 g^{-1}) compared to volcanic soil (7.62 me 100 g^{-1}). Exchangeable K and Mg were moderate in volcanic soil (0.43 me 100 g^{-1} and 1.36 me 100 g^{-1}, respectively) and lower in sediment soil (0.22 me 100 g^{-1} and 0.45 me 100 g^{-1}). Both soil types exhibited low cation exchange capacity (CEC), with values of 16.38 and 15.17 me 100 g^{-1} for volcanic and sediment soils, respectively. Both soils showed low water content (2.43% and 1.91%) and differed in texture, with volcanic soil classified as sandy clay loam and sediment soil as loam.

Both of the research locations have low rainfall distribution and intensity. Figure 1 displays the monthly rainfall, number of rainy days, and the cropping pattern for Situbondo and Sumenep Regency.



(A) (B)

Figure-1. Data of monthly rainfall and number of rainy days, with illustration of each treatment's cropping patterns on volcanic soil of Situbondo (A) and sediment soil of Sumenep (B) drylands. Note: D. Row = double row

The highest rainfall in Situbondo was recorded in January, reaching 415 mm, followed by 344 mm in February. Rainfall then declined sharply from March onward and remained below 50 mm per month in May and June. The monthly rainfall from May to November in this area was consistently below 100 mm, indicating a long dry period. The number of rainy days followed a similar trend, with peaks in January (18 days) and February (14 days), decreasing gradually to fewer than 5 days per month during the dry season (June–September).

Sumenep received more rainfall at the peak rainy season (January to February) than Situbondo, recorded at 513.4 mm and 529.5 mm, respectively. The area received less than 100 mm rainfall consecutively from May to June, with no rain in August and September. There were 16–17 rainy days during the peak rainy season (January–February) and fewer than 5 days from May to July, eventually reaching zero in August and September.

The cropping pattern occupies the same timeframe at both locations. The first planting for all treatments begins at the same period, which was scheduled before the peak of the rainy season in January and February. Intercropping occurred in the second planting of treatments C and F, where two types of crops were grown simultaneously. Cropping pattern treatments D and E demonstrated the application of relay planting, in which corn and soybean for the third planting were sown before the second planting season had ended, resulting in a slight overlap between crop cycles.

Cropping system and pattern

The results of the ANOVA analysis show that all treatments related to farming systems and cropping patterns for rice, corn, and soybeans have a significant effect on crop yields in both volcanic and sediment soils (see Table 3).

In the dry season, cropping systems on Volcanic soil (Sitobondo) produced significantly better yields than the those on Sediment soil (Sumenep) (Table 4) for most monoculture and intercropping systems. Monoculture rice under a double row system reached 8.6 t ha^{-1} dry grain on volcanic soil, which was four times greater than the yield of the same system on sediment soil (2.2 t ha^{-1}). Similarly, monoculture corn under double row yielded 7.5 t ha^{-1} on volcanic soil, compared to 5.5 t ha^{-1} on sediment soil.

The performance of intercropping systems varied between soil types. The rice (double row)-corn intercrop on the volcanic soil produced high yields of both rice (8.2 t ha^{-1}) and corn (2.1 t ha^{-1}). The same system in sediment soil, however, only produced 3.6 t ha^{-1} of rice, while the corn yield (2.5 t ha^{-1}) was comparable to that on volcanic soil. In contrast, the corn-soybean intercrop performed slightly better on sediment soil, yielding 2.8 t ha^{-1} of corn and 2.4 t ha^{-1} of soybean, compared to 2.2 t ha^{-1} and 2.0 t ha^{-1}, respectively, on volcanic soil.

The LER analysis revealed the most efficient system for each soil type. According to Anshori et al. (2022), planting in dryland areas is usually limited to twice a year, one crop is rice in the rainy season. To raise dryland agricultural production, it is necessary to increase the cropping index.

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Table-3. Analysis of Variance (ANOVA) of yields under various cropping systems for rice, corn, and soybeans on volcanic soil dan sediment soil.

			VOLCANIC SOIL				
Rice yields							
Source of Variation	*df*	*SS*	*MS*	*F-value*	*F-table 5%*	*P-value*	*Signif.*
Cropping System	2	14.9288	7.4644	10.4540	5.1432	0.0111	*
Block	3	0.4305	0.1435	0.2010		0.8921	
Error	6	4.2841	0.7140				
Total	11	19.6434					
Corn yields							
Source of Variation	*df*	*SS*	*MS*	*F-value*	*F-table 5%*	*P-value*	*Signif.*
Cropping System	4	103.0964	25.7741	43.2855	3.2592	4.902E-07	**
Block	3	3.2966	1.0989	1.8455		0.1927	
Error	12	7.1453	0.5954				
Total	19	113.5384					
Soybean yields							
Source of Variation	*df*	*SS*	*MS*	*F-value*	*F-table 5%*	*P-value*	*Signif.*
Cropping System	1	0,1701	0,1701	16.1894	10.1280	0.0774	*
Block	3	0,0315	0,0105	1		0.5	
Error	3	0,0315	0,0105				
Total	7	0.2332					
			SEDIMENT SOIL				
Rice yields							
Source of Variation	*df*	*SS*	*MS*	*F-value*	*F-table 5%*	*P-value*	*Signif.*
Cropping System	2	1.3857	0.6928	7.1735	5.1433	0,0256	*
Block	3	0.2627	0.0876	0.9068		0.4913	
Error	6	0.5795	0.0966				
Total	11	2.2279					
Corn yields							
Source of Variation	*df*	*SS*	*MS*	*F-value*	*F-table 5%*	*P-value*	*Signif.*
Cropping System	4	39.3170	9.8293	58.3691	3.2529	9.152E-08	**
Block	3	1.2695	0.4232	2.5129		0.1079	
Error	12	2.0208	0.1684				
Total	19	42.6073					
Soybean yields							
Source of Variation	*df*	*SS*	*MS*	*F-value*	*F-table 5%*	*P-value*	*Signif.*
Cropping System	1	0.0419	0,0419	16,9627	10.1280	0.0259	*
Block	3	0.0199	0,0066	2,6789		0.2199	
Error	3	0.0074	0,0025				
Total	7	0.0692					

Notes: df: degrees of freedom, SS= sum of squares, MS = mean square. **: significantly different α = 0.001, * significantly different at α = 0.05, ns= not significantly different.

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Table-4. Yield and LER of various rice, corn, and soybean cropping systems on volcanic soil (Suitubondo) and sediment soil (Sumenep) drylands in the dry season.

Cropping system	Volcanic soil				Sediment soil			
	Rice	**Corn**	**Soybean**	**LER**	**Rice**	**Corn**	**Soybean**	**LER**
	t ha^{-1} dry grain	**t ha^{-1} dry grain**	**t ha^{-1} dry grain**		**t ha^{-1} dry grain**	**t ha^{-1} dry grain**	**t ha^{-1} dry grain**	
● Rice	6.0 b	-	-	1	3.9 b	-	-	1
● Rice double row	8.6 a	-	-	1	4.3 a	-	-	1
● Rice double row +	8.2 a	-	-	1.26	3.6 b	-	-	1.34
Corn	-	2.1 b	-		-	2.5 b	-	
● Corn//	-	6.7 a	-	1.12	-	5.0 a	-	1.18
Corn		5.4 a				5.9 a		
● Corn double row// Soybean	-	7.5 a	2,0	1.44	-	5.5 a	2,4	1.48
● Corn +	-	2.2 b	-	1.24	-	2.8 b	-	1.52
Soybean	-	-	2.0 a		-	-	2.4 a	
● Soybean	-	-	2.2 a	1	-	-	2.5 a	1
C V (%)	8.65	19.57	4.05	-	17.40	12.63	3.42	-

The performance of rice, corn and soybean planting systems and patterns is influenced by the technology applied and the environmental conditions for growth, both in volcanic soil and in sediment soil. The REY result across all the planting seasons is presented below (Table 5, Figure 2).

Table-5. The performance of various rice, corn and soybean planting systems in an integrated cropping pattern on volcanic soil (Situbondo) and sediment soil (Sumenep) drylands.

Treatment	Cropping System and Pattern	Volcanic Soil				Sediment Soil			
		Planting season			REY	Planting season			REY
		1st	2nd	3rd		1st	2nd	3rd	
		(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})
A	Rice – Rice	8.0	6.0	-	14.0	4,9	3.9	-	8,8
B	Rice – Rice double row	8.0	8.6	-	16.6	4,9	4.3	-	9,2
C	Rice – Rice double row + Corn	8.0	8.2 2.1	-	17.9	4,9	3.6 2.5	-	10.6
D	Rice – Corn // Corn	8.0	6.7	5.4	18.1	4,9	5.0	5.9	13.4
E	Rice – Corn double row //Soybean	8.0	7.5	2.0	17.1	4,9	5.5	0.5	10.2
F	Rice – Soybean + Corn	8.0	2.0 2.2	-	12.7	4,9	2.4 2.8	-	10.6
G	Rice – Soybean – Corn	8.0	2.2	6.5	16.5	4.9	2.5	7.4	14.6

Note: Price: Rice = IDR. 4,200/kg dry grain; Corn = IDR. 3,500/kg dry seed; Soybean = IDR. 6,000/kg dry seed; REY = Rice Equivalent Yield

The highest REY calculated in volcanic soil was from the rice-corn//corn system (18.1 t ha-1), followed by the rice-rice double row/corn system. in contrast, the rice-soybean-corn systems yielded the lowest REY (12.7 t ha-1). Monoculture rice in a single row for two seasons produced a yield of 14.0 t ha-1, which was lower than the 16.6 t ha-1 yield from a system of rice followed by rice double row. However, both of these were outperformed by systems that followed the first rice season with either a rice double row-corn intercropping (17.9 t ha-1) or a corn-soybean relay cropping (17.1 t ha-1). Soybean-corn intercropping in the second planting season produced the least satisfactory yield, with a total REY of only 12.7 t ha-1. On sediment soil, the REY values for all systems were lower than on volcanic soil. The highest REY was recorded in the sequential rice-soybean-corn system (14.6 t ha-1), with the rice-corn//corn cropping system being the second best (13.4 t ha-1) on this soil. Both rice monoculture systems performed poorly, yielding only 8.8 t ha-1 (rice-rice) and 9.2 t ha-1 (rice-rice double row). The comparison of REY for both locations is illustrated in Figure 2 below.

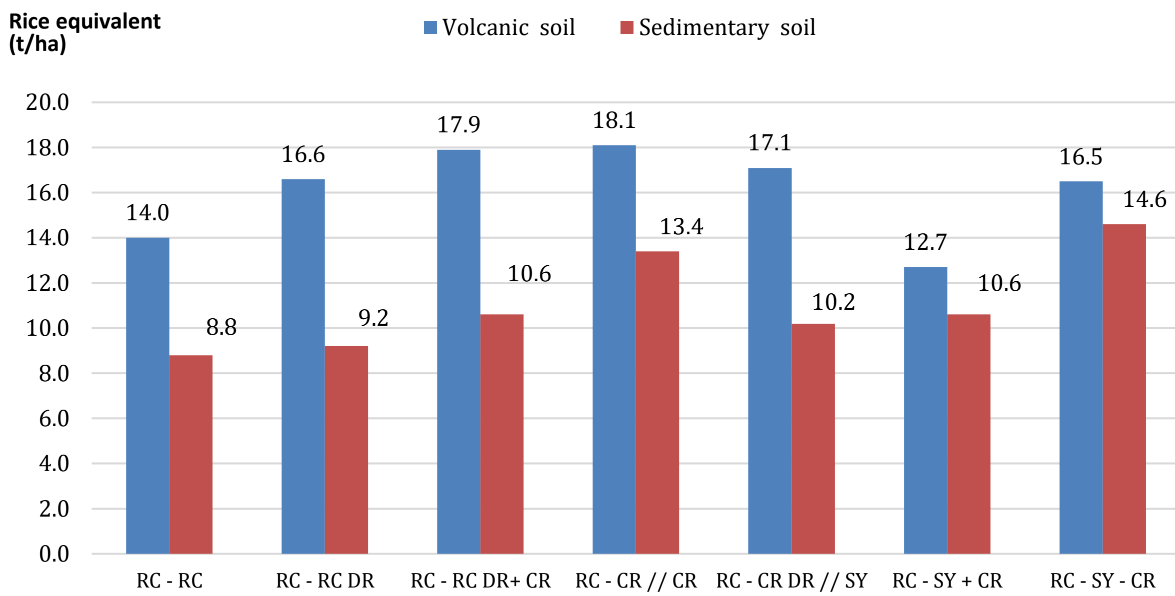

Figure-2. Rice Equivalent Yield from cropping systems and patterns on dryland volcanic soil (Situbondo) and sediment soil (Sumenep). RC: rice, CR: corn, SY: soybean, DR: double row.

Overall, the arrangement of rice, corn, and soybean monoculture and intercropping into various cropping systems in volcanic soil (Situbondo) achieved higher result than on the sediment soils (Sumenep). The graph shows that REYs on the volcanic soil are consistently higher than the yields from the cropping systems in sediment soil.

The increase in REYs from cropping systems and patterns is influenced by actual land use. Actual land use is based on area and time perspectives of rice, corn and soybean crop systems and patterns through the measurement of Cropping Intensity Index (CII) (Table 6, Figure 3).

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Table-6. Cropping intensity index (CII) and cropping intensity (CI) of rice, corn and soybean cropping systems and patterns on dry land volcanic soil (Situbondo) and sediment soil (Sumenep).

Treat-ment	Cropping System and Pattern	Volcanic Soil					Sediment Soil				
		Age (days)	Cumula-tive (days)	CII	Area/ plant (Ha)	CI	Age (days)	Cumula-tive (days)	CII	Area/ plant (Ha)	CI
A	Rice – Rice	115 115	230	0.63	1,0 1,0	200	115 115	230	063	1,0 1,0	200
B	Rice – Rice double row	115 115	230	0.63	1,0 1,0	200	115 115	230	0.63	1,0 1,0	200
C	Rice – Rice double row+Corn	115 115	230	0.63	1,0	200	115 115	230	0.63	1,0	200
D	Rice – Corn // Corn	115 100 85	300	0.82	1,0 1,0 0,85	285	115 95 85	290	0.79	1,0 1,0 0,85	285
E	Rice – Corn double row // Soybean	115 100 85	300	0.82	1,0 1,0 0,85	285	115 95 85	290	0.79	1,0 1,0 0,85	285
F	Rice – Soybean + Corn	115 100	215	0.59	1,0 1,0	200	115 95	210	0.57	1,0 1,0	200
G	Rice – Soybean – Corn	115 88 100	303	0.83	1,0 1,0 1,0	300	115 84 95	294	0.80	1,0 1,0 1,0	300

Treatment G involves the longest cumulative cropping period and the most intensive land use across both soil types. It produced CII of 0.83 and CII 300 on volcanic soil, and CII 0.80 with CI 300 on sediment soil. Treatments D and E followed closely behind, with CII values of 0.82 and CI 285 on volcanic soil, and CII 0.79 with CI 285 on sediment soil. These values indicate practices close to year-round cropping. In contrast, treatments A–C and F had CII values of 0.57–0.59 and CI 200, involving three planting and harvesting periods. The time required for land preparation and harvesting processes also needs to be considered. This suggests that land use intensity could be increased further through more intensive crop management and guaranteed water availability during crop growth in the dry season.

Figure 3 illustrates the time taken for the cropping systems in both locations. The cumulative cropping periods on volcanic soil are longer and have higher CII values than on sediment soil. This indicates that crops can be grown for longer or more frequently there.

Farming analysis of rice, corn and soybean

Table 7 provides an analysis of rice, corn and soybean farming under various crop management systems. The table provides analyses of volcanic and sediment soil during the second planting season (dry season). The results showed that monoculture rice cultivation in double row or rice intercropping (double row) with corn were more profitable than the other cropping systems tested.

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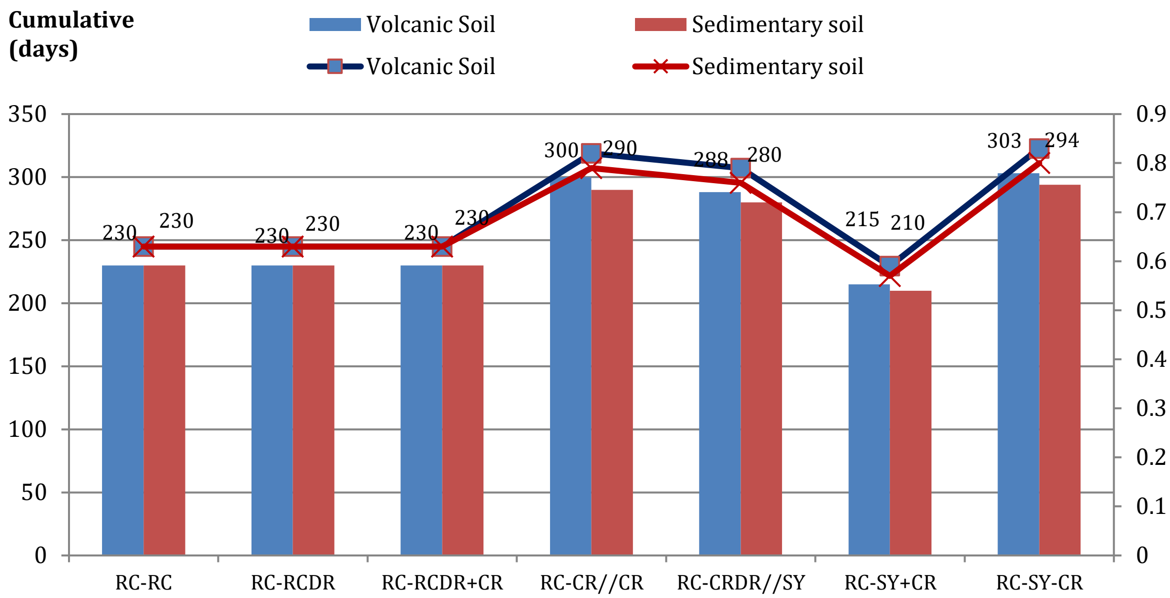

Figure-3. Time of land use and CII values on dry volcanic soil (Situbondo) and sediment soil (Sumenep). RC: rice, CR: corn, SY: soybean, DR: double row.

Table-7. Farming analysis of various crop management on dryland volcanic soil (Situbondo) and sediment soil (Sumenep), in the second planting time (dry season).

Activity	Rice		Rice double row		Rice double row + corn		Corn		Corn double row		Soybean + corn		Soybean	
	Volc.	Sedim.	Volc.	Sedim.	Volc.	Sedim.	Volc.	Sedim.	Volc.	Sedim.	Volc.	Sedim.	Volc.	Sedim.
A. Labor														
1. Soil tillage	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200
2. Planting	1,800	1,625	2,040	1,690	2,400	2,275	1,320	1,170	1,560	1,430	1,440	1,950	1,200	1,560
3. Fertilization	480	450	480	450	480	450	480	450	480	450	480	300	480	300
4. Weeding	2,100	3,640	2,100	3,640	2,100	3,640	1,200	1,560	1,200	1,560	1,500	1,625	1,500	1,625
5. Spraying	360	300	360	300	360	300	240	150	240	150	240	150	240	150
6. Irrigation	300	1,800	300	1,800	300	1,800	240	900	240	900	240	900	240	450
7. Harvesting	1,440	2,815	1,440	3,020	1,800	3,925	1,080	1,725	1,200	1,820	720	2,470	720	1,900
8. Post harvest	720	1,305	780	1,510	980	750	720	650	720	780	840	910	720	550
B. Prod.facilities														
1. Seed :														--
- Rice	360	360	450	360	450	450	-	-	-	-	-	-		
- Corn	-	-	-	-	450	450	900	900	900	900	450	450	-	-
- Soybean	-	-	-	-	-	-	-	-	-	-	360	360	360	360
2. Fertilizer :	-	-	-	-	-	-	-	-	-	-				
- Organic	1,000	1,000	1,000	1,000	1,000	1,000	500	500	500	500	500	500	500	500
- Urea	360	360	360	360	360	360	450	450	450	450				
- Phonska	575	575	575	575	575	575	575	575	575	575	575	575	575	575
- Agrimeth	-	-	60	60	60	60	-	-	-	-	-	-	-	-
- Agrisoy	-	-	-	-	-	-	-	-	-	-	100	100	100	100
- M-Dec	-	-	40	40	40	40	-	-	-	-				
3. Pesticide	240	240	240	240	300	300	120	120	100	120	100	100	100	100
Prod.cost	10,735	15,670	11,225	16,245	12,655	17,575	8,825	10,350	9,165	10,835	8,545	11,680	7,735	9,370
Rice income	25,267	16,380.0	35,952	18.060	34,234.2	15,120	-	-	-	-	-	-	-	-
Corn income	-	-	-	-	7,322	8,750	23,478	17,353	26,397	19,365.5	7,612.5	9,712.5	-	-
Soybean income	-	-	-	-	-	-	-	-	-	-	11,748	14,310	13,002	15,000
Total income	25,267	16,380.0	35,952	18,060	41,556.2	23,870	23,478	17,353	26,397	19,365.5	9,560.5	24,022.5	13,002	15,000
Profit	14,532	710.000	24,727	1,815,0	28,901.2	6,295	14,653	7,003	17,232	8,530.5	1,015.5	12,342.5	5,267	5,630
R/C Ratio	2.35	1.04	3.20	1.11	2.28	1.36	1.65	1.67	1.88	1.78	2.25	1.06	1.68	1.60

Notes: Volc. = Volcanic soil (Situbondo); Sedim. = Sediment soil (Sumenep). Price of rice (dry grain): IDR. 4,200/kg; corn (dry grain): IDR. 3,500/kg; Soybean (dry grain): IDR. 6,000/kg.

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The highest R/C ratio was obtained from rice double row system on volcanic soil (3.10), indicating it was the most profitable. On the same soil type, rice monoculture and intercropping of rice double row with corn gave similar results, with R/C ratio of 2.35 and 2.28, respectively. The least profitable system on volcanic soil was the sole crop of corn, with R/C ratio of 1.65.

In contrast, the R/C ratios of all systems on sediment soils were lower than those on volcanic soil. The highest R/C ratio on this soil was obtained from the sole crop of soybean (1.60) which was only slightly lower than the same system on volcanic soil (1.68). The soybean+corn intercropping was only marginally profitable, with R/C ratio of 1.06. Other systems were considered not economically feasible, as their R/C values were below 1.

Discussion

Climate data presented in Figure 2 indicates that both Situbondo and Sumenep Regencies experienced dry climates. Situbondo Regency is classified under Oldeman E3 climate type with 2 wet months and 6 dry months, while Sumenep Regency is under Oldeman C3 climate type with 5 wet months and 5 dry months.

Table 3 shows that the highest yields of food crop planting systems on volcanic soil (Situbondo) were in double-row monoculture rice (8.6 t ha^{-1} of dry grain), double-row corn (7.5 t ha^{-1} of dry grain), and monoculture soybeans (2.2 t ha^{-1} of dry grain). Meanwhile, in the food crop planting system on sediment soil (Sumenep), the highest yields of double-row rice were only 4.3 t ha^{-1} of dry grain, double-row corn 5.5 t ha^{-1} of dry grain, and monoculture soybeans 2.5 t ha^{-1} of dry grain. The low yields of food crop planting systems on sediment soil (Sumenep) were caused by reduced air circulation during plant growth which was highly dependent on rain. Planting monoculture rice or double-row corn with a larger plant population compared to planting regular rice and corn resulted in higher rice and corn yields. Although cropping management decisions impact the design of intercropping system, the performance of intercrop is ultimately determined by the availability of environmental resources and competition (Wang et al., 2014; Wu et al., 2021).

In sediment soils with severe water limitations, intercropping does not always increase productivity because water limitations can cause crops to compete with each other rather than complement each other. When the component crops have overlapping water requirements, particularly within the same root zone, competition for soil water can outweigh the benefits of resource sharing. Consequently, the total productivity of intercropping may be lower than that of an optimised monoculture, particularly if planting distances, plant populations and species combinations do not reduce water competition (Kamara et al., 2019; Cai et al., 2022; Erythrina et al., 2022; Wang et al., 2022).

In general, monoculture system in this study yielded higher crop production than intercropping system. Intercropping increases competition for resources, such as light, nutrient, and water (Stomph et al., 2020), which might contribute to the reduced yield. Intercropping of species with different canopies architecture led to reduced light interception and light use efficiency, especially for shorter crops (Wang et al., 2021). However, below-ground competition for nutrient and water resources can impacts total yields more than above-ground competition for sunlight (Lv et al., 2014).

The LER analysis revealed that intercropping systems on volcanic soil (Situbondo), specifically soybean + corn and rice + corn, produced LER values > 1, indicating a land-use advantage. For relay cropping of corn (corn//corn) on volcanic soil, the LER was 1.12, corresponding to a 12% land-use advantage, slightly lower than that on sediment soil (LER = 1.18). Furthermore, relay planting of corn double row // soybean achieved higher LER values of 1.44 on volcanic soil and 1.48 on sediment soil. This indicates that the insertion of corn or soybean using the relay method was carried out 15 days before the main crop (corn) was harvested. Therefore, in the LER calculation, the growth period of the inserted crops that overlap with the main crop is proportionally accounted for, allowing the intercropping system to gain yield benefits during the overlapping period.

This shows that relay planting of corn in two stages is a more efficient use of the land, resulting in high crop yields. A LER value that is greater than 1 indicates intercropping yield advantage over monoculture (Toker et al., 2024). According to Zhang et al. (2015), intercropping of corn and soybeans provided significant results with greater economic benefits, increased LER, and reduced soil nitrate accumulation. Furthermore, Ginting et al. (2023) reported that the intercropping of soybeans with corn planted together showed higher total LER values, yields and profits compared to monoculture of corn or soybean. The study by Yu et al. (2015), in which the LER of intercropping pattern is around 1.22 with the average of 1.32, further confirmed intercropping system's productivity. Additionally, studies have also documented that intercropping of soybean-corn, and rice-corn has increased LER and farm income (Arifin et al., 2014; Arifin and Krismawati, 2020), thus further reinforced the benefits of intercropping.

As detailed in Table 5 and further highlighted in Figure 2, the analysis of farming systems on different soil types reveals distinct optimal planting patterns for maximizing yield, measured in REY. The optimal yield on volcanic soil (Situbondo) can be produced by rice-corn//corn cropping system (18.1 t ha^{-1} REY), closely followed by the rice - rice double row + corn pattern (17.9 t ha^{-1} dry grain). In contrast, the best cropping system to apply in sediment soil (Sumenep) is rice-soybean-corn planting system with a REY yield of 14.6 t ha^{-1}, followed by rice-corn//corn pattern with 13.4 t ha^{-1} REY.

This finding aligns with the result of Fagi and Partohardjono's (2004) study, which showed the best cropping pattern on dryland to be a relay planting system of rice + corn + peanuts. The relay planting pattern is a more productive intercropping system because it allows for bigger and varied plant population.

Table 6 and Figure 3 illustrate how annual cropping patterns affect the land use duration, which is determined by crop management practices and growth cycles. On volcanic soil (Situbondo), the rice-corn//corn pattern, which yields the highest rice equivalent, also requires the longest land use duration at 300 days. Conversely, the highest-yielding pattern on sediment soil (Sumenep), rice-soybean-corn, only requires 294 days. The cropping intensity index (CII) is determined by land use within a year for a given cropping system. The CII value will increase the more crops grown in rotation or sequence. The rice-corn//corn and rice-soybean-corn patterns achieved the highest CII values on volcanic soil (0.82 and 0.83, respectively), leaving 17-18% of the year available for additional planting. On sediment soil, the same patterns resulted in lower CII values (0.76 and 0.80), indicating a larger window of 20-24% of the year for subsequent crops.

According to Table 7, the production and profitability of crops on volcanic soil (Situbondo) is considerably greater than on sediment soil (Sumenep). For instance, the rice double row monoculture system on the volcanic soil (Situbondo) produced 8.6 t ha^{-1} of dry grain, demonstrating the fertile volcanic soil under rice monoculture provided better growing conditions. Volcanic soil contains considerable reserves of the most important nutrients (N, P, and K), has better soil structure and greater water retention which allows for sustained growth and dry season irrigation. This is in direct contrast to the yield (2.2 t ha^{-1} dry grain) produced on sediment soil (Sumenep) under the same system. This is primarily due to water deficits (during the growth period), because soil moisture is lost faster to the atmosphere and plant stress during dry spells is more severe due to lower organic matter content sediment soils and, thus, lower moisture retention.

Based on a study by Turmudi (2002), drought-related water scarcity can increase competition among plants for water and nutrients and compromise crop yields. It offers a partial explanation for the performance difference observed among soybean and the other three water-stressed crops growing on sediment soils. Soybean outperformed the other three crops, likely because they had shallow roots, less drought tolerance, and were more sensitive to extended dry periods. Soybean's pronounced ability to modify its root morphology to extract water from deeper soils keeps its root-active and physiologically less drought stressed. Support for this claim is provided by Fan et al. (2025) who noted that, under monocropping conditions, soybean more consistently develops deeper root systems than maize, allowing for enhanced water uptake and increased resilience to drought.

The most profitable cropping systems during the dry season differed according to soil type. On volcanic soil, the rice double row system was optimal, producing 8.6 t ha^{-1} of dry grain with a net profit of IDR 24,727,000 and an R/C ratio of 3.20. The high yield and profitability were driven by the soil's superior fertility, stable moisture conditions, and efficient use of available nutrients under the double row planting arrangement, which enhanced light interception and tiller production. Conversely, on sediment soil, the soybean monoculture system was more advantageous, yielding 2.5 t ha^{-1} with a profit of IDR 5,630,000 and an R/C ratio of 1.60. The moderate profitability of soybean on sediment soil reflects its adaptability to dry environments and its relatively low input requirements, which make it a more sustainable choice under limited water availability.

Conclusion

Site-specific cropping systems can significantly improve the productivity and land-use efficiency of drylands, as well as farmer profitability, on both volcanic and sediment soils. In Situbondo, the rice–corn/corn relay pattern performed best on volcanic soil, producing the highest rice equivalent yield of 18.1 t ha^{-1} with a CII of 0.82 and CI 285. In Sumenep, the most suitable pattern on sediment soil was rice–soybean–corn, producing 14.6 t ha^{-1} with a CII of 0.80 and CI 300. Relay and intercropping systems increased land-use efficiency, as demonstrated by LER values exceeding 1. The highest values were achieved with corn double row relay planting with soybean, reaching 1.44 on volcanic soil and LER 1.48 or corn + soybean LER 1.52 on sediment soil. In economic terms, the most profitable system on volcanic soil was rice double row, while the highest profit was achieved with corn double row on sediment soil. The main impact of the study is that drylands with limited water and soil fertility can support productive and profitable agriculture when managed using adaptive, location-specific crop arrangements. The study's novelty lies in its integration of yield performance, land-use efficiency, cropping intensity and economic feasibility in order to identify sustainable cropping patterns for contrasting dryland soil types. Overall, the manuscript confirms that optimized cropping patterns, relay planting, and double row systems can support sustainable dryland agriculture and improve farmer prosperity.

Limitations of Study

The scope of this activity is limited to dryland on volcanic soil (Situbondo) and sediment soil (Sumenep) in East Java, Indonesia. Future research can expand the scope of this activity to soil types that have different agroecosystems in the East Java region, Indonesia. By knowing the limitations and potential of dry land agroecosystems, food cropping systems and patterns can be arranged to increase production and income from food crop farming income in one cropping pattern unit.

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Conflict of Interest: None.

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Data Availability Statement

The data will be available on request.

Contribution of Authors

Rejekiningrum P & Arifin Z: Conceptualization, analyzing data, literature search, writing and editing initial manuscript.

Latifah E, Krismawati A & Tafakresnanto C: Conceptualization, writing and editing the initial manuscript.

Antarlina SS: Analyzing data, writing and editing initial manuscript.

Saeri M, Baswarsiati & Setyorini D: Literature search, wrote and edited the initial manuscript.

Alifia AD: Literature search, visualization, writing and editing the manuscript.

All authors contributed equally, read and approved the final draft of the manuscript.

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