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RESEARCH ARTICLE
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Optimizing Dryland Agriculture: Intercropping Corn and Superior Rice Varieties in Maluku, Indonesia

Wahid [1], La Karimuna [2,*], Asmin [1], Baharuddin [1], Samijan [1], August Lexi Polakitan [1], Rachmiwati Yusuf [1], Putri Tria Santari [1], Mirawanty Amin [1], Wahyu Adi Nugroho [1], Yulis Hindarwati [1], Sodiq Jauhari [1], Kalis Amartani [3], Melati [4] and Hasddin [5,*]

[1] Research Center for Food Crops, Research Organization for Agriculture and Food, National Research and Innovation Agency. Jakarta, Indonesia
[2]Department of Agrotechnology, Faculty of Agriculture, University of Halu Oleo, Jl. H.E.A. Mokodompit 93232, Kendari, Southeast Sulawesi Province, Indonesia
[3]Department of Agribusiness, Faculty of Agriculture, University of Lakidende Unaaha, Southeast Sulawesi, Indonesia
[4]Department of Management, Faculty of Economic and Business, Lakidende University Unaaha, Southeast Sulawesi, Indonesia
[5]Department of Agribusiness, Faculty of Agriculture, University of Lakidende Unaaha, Indonesia
*Corresponding author: hasddinunilaki@gmail.com; lkarimuna63@gmail.com

ABSTRACT

Dryland agriculture faces significant challenges, particularly in tropical regions like Indonesia, due to climate variability and the gradual decline in productive land. One potential solution to enhance agricultural efficiency in these areas is the practice of intercropping. This study examines an engineered management approach that involves intercropping superior maize varieties with high-yielding upland rice varieties to optimize land use and productivity. The experiment was conducted at the Makariki Experimental Garden of the Food Crops Research Center, Maluku, from May to September 2020, using a Randomized Block Design with five treatments and five replications. The intercropping treatments consisted of maize (Nasa 29) combined with five different upland rice varieties: (1) Inpago 8, (2) Inpago 11, (3) Inpago 12, (4) Rindang 1, and (5) Rindang 2. For comparison, monoculture plots of maize (Nasa 29) and monoculture plots of the respective upland rice varieties were also evaluated. Results indicated that intercropping significantly increased maize productivity by 142% compared to monoculture systems. However, upland rice productivity declined by 72% under intercropping conditions. Despite this reduction, all five upland rice varieties (Inpago 8, Inpago 11, Inpago 12, Rindang 1, and Rindang 2) demonstrated suitability for intercropping with maize, as the system improved overall land productivity. The Land Equivalent Ratio (LER) values ranged from 2.11 to 2.45, indicating an increase in dryland productivity by 111–145% compared to monoculture cultivation. These findings confirm that intercropping maize with high-yielding upland rice varieties enhances both land use efficiency and overall crop yield productivity. This approach presents a viable strategy for optimizing dryland agriculture, making better use of available resources while sustaining productivity.

Keywords: Corn; Dry land; Intercropping; Productivity; Upland rice.

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INTRODUCTION

The conversion of fertile farmland for urban, industrial, and infrastructural development has sharply reduced rice paddy fields, posing a serious threat to global agricultural efficiency. As the demand for land increases, food security becomes ever more urgent, prompting the need for innovative, sustainable farming strategies. Researchers have identified dryland agriculture as a promising alternative that can maintain food production while enhancing environmental resilience (Alexander et al., 2015; Kusbiantoro et al., 2018; Sahara & Kushartanti, 2019; Jiang et al., 2019; Jumakir et al., 2019; Adnan et al., 2020; Hartati, 2020; Merang et al., 2020; Jamal et al., 2023).

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These strategies align with the sustainable development agenda, which aims to ensure food availability and ecological balance (Khanom, 2016; Kamruzzaman & Shaw, 2018; Adenle et al., 2019; Thakur et al., 2021).

In this context, Maluku, Indonesia, presents significant potential for dryland agriculture, particularly for upland rice cultivation. The Central Bureau of Statistics of Maluku Province (2020) reports that about 847,601 hectares are suitable for dryland farming; however, only roughly 305,136 hectares (36%) are currently utilized. This underutilization not only reflects inefficient use of available resources but also highlights an opportunity to boost productivity and food security by harnessing the remaining 64% of land. Despite this potential, upland rice farming in Maluku suffers from low productivity. Between 2015 and 2019, average yields were only 2.73 t/ha, far below the potential of 7.0 t/ha (Central Bureau of Statistics of Maluku Province, 2020). Factors contributing to this yield gap include limited access to improved seed varieties, slow adoption of modern farming techniques, inadequate irrigation, soil fertility issues and climate variability. Additionally, many smallholder farmers lack the training and resources needed to adopt better practices, further hindering productivity.

One promising solution to these challenges is intercropping. This method involves cultivating two or more crops on the same field simultaneously or sequentially, thereby maximizing the use of available resources. Research indicates that intercropping can enhance land use efficiency, improve soil fertility, and reduce the risks associated with crop failure (Paudel, 2016; Karimuna, 2011; Iwuagwu et al., 2019). Unlike monoculture systems, which can lead to soil degradation and increased pest problems, intercropping creates a more resilient and sustainable farming system through crop diversification.

Various intercropping arrangements are available. Row cropping, alternate cropping, and mixed cropping are among the common methods. The success of intercropping depends on pairing crops with complementary growth patterns. For example, combining legumes with cereals is advantageous because legumes fix atmospheric nitrogen, thereby enriching the soil and reducing the need for synthetic fertilizers. Such strategic pairing optimizes water, light, and nutrient use while creating a microenvironment that supports overall ecosystem health (Matusso et al., 2013; Karimuna, 2011; Hairmansis et al., 2022).

Intercropping offers several clear benefits. It increases overall land productivity by making efficient use of space and resources, leading to higher yields per unit area (Eka et al., 2021). Additionally, the diversity of crops can improve soil quality through varied root systems that prevent compaction and promote nutrient cycling. Leguminous crops, for instance, naturally boost soil nitrogen levels, reducing dependency on chemical fertilizers (Aisyah & Herlina, 2018). Furthermore, diverse cropping systems help control weeds and pests by disrupting their life cycles, which lowers the need for herbicides and pesticides and enhances environmental sustainability (Ceunfin et al., 2017). By reducing the risk of total crop failure, intercropping also increases climate resilience and stabilizes yields under adverse conditions (Matusso et al., 2014a). Economically, lower input costs—from reduced fertilizer and pesticide use—can translate to increased profitability for farmers. The Land Equivalent Ratio (LER) is frequently used to quantify these benefits, with an LER greater than one indicating that intercropping is more efficient than monoculture (Li et al., 2011; Matusso et al., 2014b; Lestari et al., 2019; Karimuna et al., 2022).

However, to fully realize the potential of intercropping in Maluku, the adoption of high-yielding crop varieties is essential. The region's low productivity is partly due to the limited use of improved upland rice varieties among farmers (Riyanto et al., 2020). Researchers such as Musyafak et al. (2018) have identified several promising varieties for intercropping, including Situ Patenggang, Situ Bagendit, Inpago 8–12, Rindang 1, Rindang 2, and Jati Luhur for rice and varieties like Nasa 29, Bima 2, and JH 27 for corn. Integrating these high-yielding varieties can help narrow the productivity gap and unlock the full benefits of intercropping.

Beyond agronomic advantages, intercropping also delivers socio-economic and environmental benefits. Diversifying crops can stabilize farm incomes, reduce dependency on a single crop, and foster local economic development by creating new market opportunities and agro-processing ventures. Environmentally, reducing chemical inputs helps preserve biodiversity, maintain beneficial soil microorganisms, and improve water quality, contributing to broader ecosystem services crucial for sustainable agriculture. Moreover, combining modern agricultural technologies such as precision farming tools that monitor soil conditions and crop health with traditional practices can optimize intercropping systems further. This integrated approach allows for the fine-tuning of crop management to suit local environmental conditions, enhancing overall productivity and resilience. Despite its benefits, the transition to intercropping is not without challenges. Initial investments in equipment, training, and infrastructure modifications can be significant, particularly for smallholder farmers. Limited access to up-to-date research and modern technologies also poses hurdles. Additionally, market dynamics that favor single-crop production may discourage farmers from diversifying their crops. Overcoming these challenges will require coordinated efforts among researchers, policymakers, and extension services to provide the necessary support and resources.

Given the challenges and opportunities in Maluku's dryland agriculture, this study evaluates the impact of intercropping corn with superior upland rice varieties on land productivity, crop performance, and overall agricultural efficiency. The objectives are to: (1) Determine the productivity benefits of intercropping corn with upland rice varieties compared to monoculture systems; (2) Determine the land productivity of intercropping corn with upland rice varieties to maximize dryland productivity; and (3) Assess land use efficiency by analyzing the Land Equivalent Ratio (LER) and other agronomic indicators. This research aims to provide scientific evidence and practical recommendations for optimizing intercropping systems in dryland farming. The findings are expected to contribute to improved food security, sustainable land use, and agricultural efficiency, particularly in regions challenged by land conversion and climate variability.

Mapping of Novelty

The potential novelty of this study lies in its comprehensive exploration of engineering management approaches to improve agricultural efficiency in dryland areas, particularly in the context of Maluku, Indonesia. While previous studies have investigated intercropping and its benefits in dryland farming, this study focuses on the following novel aspects: *First*, Application to dryland areas of Maluku. Most of the land is still underutilized for dryland farming, particularly upland rice cultivation. This presents a unique opportunity to increase productivity in an area with substantial unrealized potential. *Second*, testing of superior varieties. This study specifically tested a range of superior maize and upland rice varieties. This study evaluated how these varieties, when intercropped, could improve land and crop productivity, addressing Maluku's suboptimal rice yields. *Third*, focus on agricultural efficiency, which is critical to improving the economic viability of dryland farming. By using the Land Equivalent Ratio (LER) as a tool to measure the benefits of intercropping, this study bridges the gap between increased yields and sustainable agricultural practices. *Fourth*, improved land and resource management. This study explores the benefits of better land use efficiency, improved soil quality, and optimal use of resources (e.g., water, nutrients, light). These factors are key to addressing challenges such as paddy field shrinkage and limited water availability, which are common in dryland farming. *Finally*, the interdisciplinary approach, where this study combines agricultural engineering, plant science, and sustainable development to propose integrated solutions that can contribute to the broader agricultural agenda, especially in line with the Sustainable Development Goals. The novelty of this study lies in its context-specific approach to dryland farming in Maluku, the use of diverse superior crop varieties, its emphasis on agricultural efficiency, and its potential to contribute to the sustainable intensification of dryland agriculture.

MATERIALS & METHODS

Location and Research Design

This study was conducted at the Makariki Experimental Garden, BPTP Balitbangtan Maluku, located in the Amahai District, Central Maluku Regency, Maluku Province (Fig. 1). The research took place between May and September 2020.

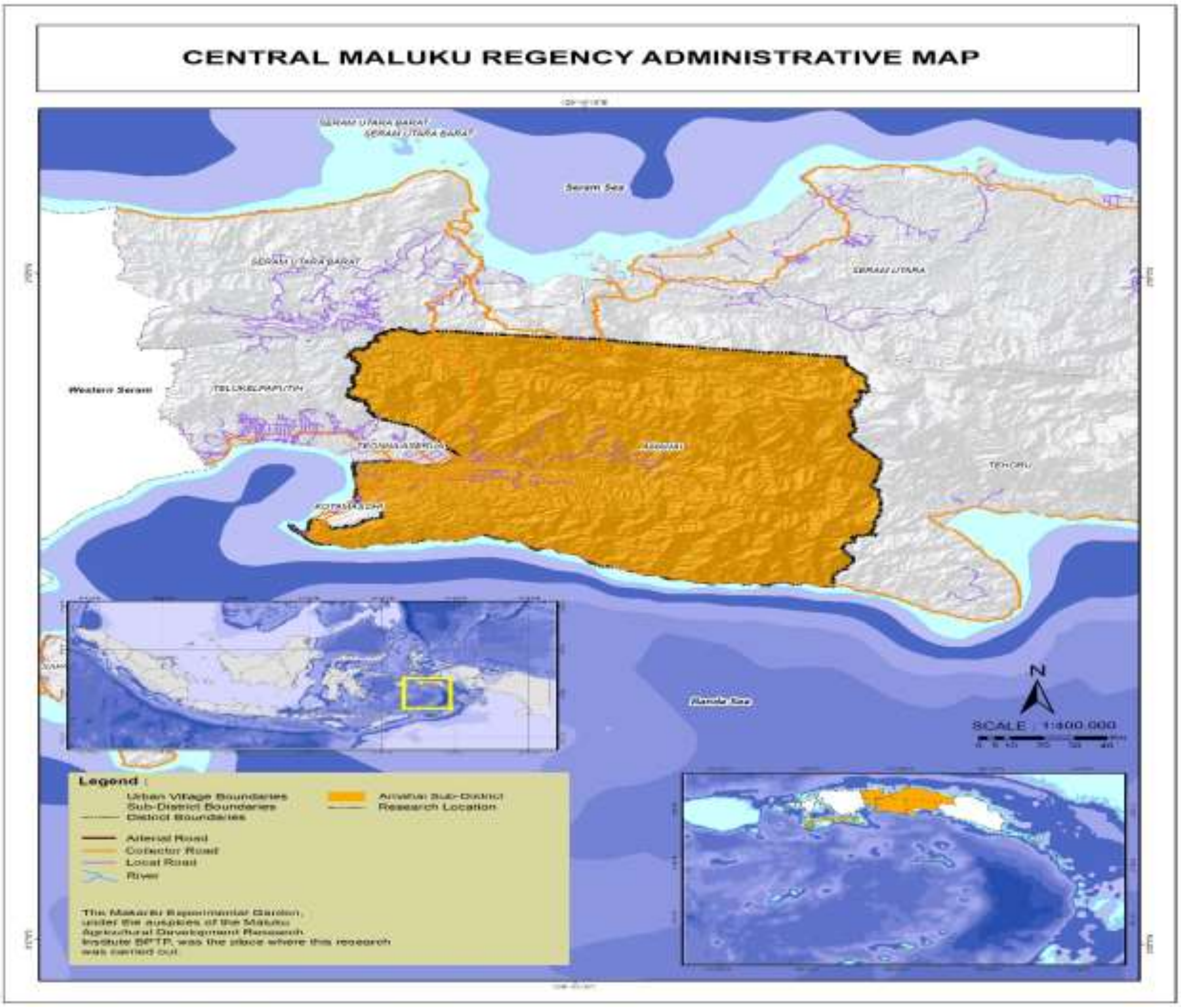

Fig. 1: Research Location, Amahai District, Central Maluku Regency, Maluku Province.

Field Experiment Design

A field experiment approach was used with a one-factor Completely Randomized Design (CRD), focusing on intercropping corn variety Nasa 29 with various upland rice varieties. The experiment included five treatments: Nasa 29 + Inpago 11 (P1); Nasa 29 + Inpago 11 (P2); Nasa 29 + Inpago 12 (P3); Nasa 29 + Rindang 1 (P4); and Nasa 29 + Rindang 1 (P5). Each treatment was replicated five times, yielding a total of 25 experimental units. As a comparison, monoculture plots of corn (Nasa 29) and NHV upland rice varieties (Inpago 8, Inpago 11, Inpago 12, Rindang 1, Rindang 2) were also included, bringing the total number of experimental units to 31.

Both monoculture and intercropping plots measured 10 x 15m, for a total area of 150m². For monoculture corn, planting was done at a spacing of 80 x 40cm (with a population of 62,500 plants per hectare (ha^{-1}), using 2 seeds per hole and requiring 20kg of seed per hectare). Monoculture upland rice was planted using the Legowo row system with a 2:1 arrangement and a spacing of 20cm x 10cm x 40cm (330,000 clumps per hectare, requiring 66kg of seed per hectare or ha^{-1}). For intercropping, corn was planted between rows of upland rice, with a spacing of 260cm x (40cm x 20cm x 50cm), resulting in a population of 110,000 plants per hectare, requiring 40kg of seed per hectare. Upland rice was planted among corn plants in 9 rows with a spacing of 140cm x (20cm x 10cm x 50cm), resulting in a population of 250,000 clumps per hectare, requiring 50kg of seed per hectare (ha^{-1}).

The fertilizer application rate was the same for both monoculture and intercropping plots. Corn received fertilization with NPK (15:15:15) at a dose of 400kg per hectare and Urea at 150kg per hectare, applied in two stages: the first at 10 Days after Planting (DAP), with NPK (200kg/ha) and Urea (50kg/ha), and the second at 30 DAP, with NPK (100kg/ha) and Urea (100kg/ha). Upland rice was fertilized starting at 25 DAP, followed by additional applications at 45 DAP and 60 DAP, with a total of 200kg per hectare of NPK and 100kg per hectare of Urea. These fertilizers were applied in three stages, with each dose divided into thirds.

Effective weed control is critical. Previous studies have demonstrated that manual weed control can be implemented during the trial period, typically at the end of the second week or the beginning of the third week (Emmanuel et al., 2021; Baidhawi, 2023). Similarly, in this study weed control was performed manually by weeding at 21 DAP and 42 DAP, with additional weeding conducted at 28 DAP, for both corn and upland rice. Pest and disease control for upland rice was done systematically, starting with Carbofuran (16kg per hectare) applied at 10 DAP and 30 DAP. During the vegetative phase, pests were controlled by spraying Fipronil (2 cc per liter of water) at 14 DAP, with subsequent applications every two weeks until the flower primordia phase. In the generative phase, beginning two weeks after the primordia stage, flowers were sprayed with Diphenoconazole (0.5 cc b.a./liter of water) every two weeks until just before harvest. For corn, Carbofuran (16kg per hectare) was applied at 21 DAP and 42 DAP to control pests and diseases.

Data Collection and Analysis

Data collection involved measuring the dry weight of seeds produced by all sample plants within the harvest plot, which was then converted to a per-hectare basis to assess land use efficiency in the intercropping system. According to Santo et al. (2023), this calculation is used to determine the Land Equivalent Ratio (LER). In this study, LER was calculated using the following equation (Islami et al., 2011):

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb} \quad (1)$$

Where:
LER : Land Equivalent Ratio
Yab : Crop yield of a in intercropping system of a and b
Yba : Crop yield of b in intercropping system of a and b
Yaa : Monoculture yield of crop a
Ybb : Monoculture yield of crop b
Farm efficiency using B/C: indicator (Khangura et al. 2023; Maitra et al. 2021):
B/C = [(Q x Pq)-(TC)]/TC (2)
Information:
B = Benefit;
C = Cost;
Q = Total yield (*quantum*);
Pq = Cost of crop (*price*);
TC = Total cost which is the sum of variable costs and fixed costs.

Decision-making rules: B/C = 1, the farmer reaches the break-even point (no profit and no loss); B/C > 1, viable and profitable farming; B/C < 1, farming is not feasible and makes a loss. The variables observed included the yield of dry grain corn and milled dry grain of upland rice per hectare (conversion from a planting plot of 7.2 m^2). Data were analyzed statistically, consisting of analysis of variance (ANOVA) to determine the effect of treatment and if significant, then continued with Duncan's Multiple Range Test (DMRT) at 95 percent (Harjadi et al., 2023).

RESULTS & DISCUSSION

Productivity of Corn and Upland Rice

The data collected from observations on the production per hectare of intercropped corn and upland rice (Turiman Jago) were converted from dry corn grain and milled dry upland rice grain per sample plot (7.2m²), as shown in Table 1. According to Table 1, the average productivity of corn in the intercropping system was higher (5.131t/ha), representing a 142% increase compared to the monoculture system (3.611t/ha^{-1}). This increase can be attributed to the higher corn population in the intercropping system (110,000 plants/ha^{-1}) compared to monoculture corn (62,500 plants/ha^{-1}).

Additionally, Table 1 indicates that intercropping Nasa 29 corn with the new high-yielding variety (NHV) of upland rice did not significantly affect the dry crop yield per hectare. The highest dry corn yield of 5.699t/ha^{-1} was recorded with the intercropping of Nasa 29 corn and Inpago 11 upland rice, followed by Nasa 29 corn intercropped with Rindang 1 (5.626t/ha^{-1}) and Nasa 29

Table 1: Yields of corn dry grain and upland rice milled dry grain on the intercropping Corn Nasa 29 and upland rice pattern. Makariki, Cropping season

Treatment	Cropping pattern				IC and M different	
	Monoculture		Intercropping		Corn (+)	Upland rice (-)
	Corn	Upland rice	Corn	Upland rice		
	.... (t ha^{-1})				.... (%)..........	
Nasa 29 + Inpago 8 (P1)		3.150a	4462a	1.833ab	124	73
Nasa 29 + Inpago 11 (P2)		2.483bc	5.699a	1.700b	158	63
Nasa 29 + Inpago 12 (P3)		2.691ab	5.423a	1.785ab	150	72
Nasa 29 + Rindang 1 (P4)		2.217bc	5.625a	2.285a	156	89
Nasa 29 + Rindang 2 (P5)		2.083c	4.444a	1.967ab	123	88
Corn Nasa 29	3.611					
Average	3.611	2.525	5.131	1.914	142	77
KK (%)		13.65	11.26	18.85		

Notes: Average values followed by different letters (a, b, and c) at the same column, were significantly different at DMRT 95 percent confident level; IC = intercropping; M = Monoculture.

with Inpago 12 (5.423t/ha^{-1}). In contrast, the lowest yields were observed in the intercropping of Nasa 29 with Rindang 2 (4.444t/ha^{-1}) and Nasa 29 with Inpago 8 (4.462t/ha^{-1}). The overall average productivity of intercropped corn was relatively low at 5.131 t/ha^{-1} (with a moisture content of 14%) compared to its potential yield of 13.7t/ha (at 15% moisture). However, this was still higher than the average productivity of farmers in Maluku, which stands at 3.20t/ha^{-1} (Central Bureau of Statistics of Maluku Province 2020).

The productivity of intercropped upland rice was significantly lower, decreasing by approximately 77%, compared to monoculture upland rice productivity (Table 1). The reduced productivity in the intercropping system can be attributed to the lower population of upland rice plants per hectare (250.000 plants/ha^{-1}) compared to the monoculture system (330.000 plants/ha^{-1}). This decrease in population is due to the wider planting distance used in intercropping (160cm x 20cm x 10cm) as opposed to the monoculture planting distance (40cm x 20cm x 10cm).

The upland Inpago 8 variety grown both monoculture and intercropped with Nasa 29 corn gave markedly higher productivity (3.150 and 2.285t/ha, respectively) compared to other new high-yielding varieties of upland rice, but differed inmarkedly from the Inpago 12 variety (2.691 and 1.785t/ha, respectively). The highest intercropping upland rice productivity (1.785t/ha) was achieved at Nasa 29 + Inpago 8 intercropping, followed by Nasa 29 + Rindang 1 (1.467t/ha) and Nasa 29 + Rindang 2 (1.333t/ha). While the lowest upland rice productivity is achieved at the intercropping of Nasa 29 + Inpago 11 (1.7t/ha). Furthermore, Table 1 shows the average productivity of upland rice achieved both in intercropping patterns (1.914t/ha) and monoculture patterns (2.525t/ha) is lower than the potential yield between 6-8t/ha (Center for Food Crop Research and Development, 2016), the highest productivity of new high-yielding varieties of upland rice planted intercropped with NASA 29 corn owned by Rindang 1 and Rindang 2.

Erythrina et al. (2022) reported that the average success rate of the rice-maize intercropping system, based on productivity, reached 44%. This indicates that while intercropping can be a viable agricultural practice, its effectiveness in maximizing yield remains limited compared to monoculture systems. Furthermore, these findings are supported by the study of Hairmansis et al. (2022), which demonstrated that rice yield was significantly higher in monoculture than in intercropping systems. This yield difference may be attributed to competition for nutrients, water, and sunlight when rice is grown alongside maize. However, among the tested genotypes, only B12056F-TB-1-29-1 exhibited the highest yield across all locations, highlighting its superior adaptability and performance under intercropping conditions. This genotype presents a promising option for farmers seeking to optimize rice production within an intercropping system, potentially enhancing land-use efficiency while maintaining relatively high productivity.

Land Productivity of Intercropping Corn Nasa 29 and Upland Rice

Land productivity is assessed using the Land Equivalent Ratio (LER), a metric that helps estimate the effects of competition and the yield advantages of different land-use systems. A LER value greater than 1 indicates that the intercropping system is more efficient in land productivity compared to monoculture. Intercropping is a cultivation system designed to increase land output by planting multiple crops on the same land within a single year (Karimuna, 2011). This approach aims to mitigate the risk of crop failure, better distribute labor throughout the year, enhance land productivity, and improve the efficient use of resources like sunlight and water (Edouard et al. 2023). According to Table 2, the LER value for the intercropping pattern (Nasa 29 + upland rice) exceeds 1.0, indicating its higher efficiency compared to monoculture.

Table 2: Values of land equivalent ratio (LER) intercropping Corn Nasa 29 and Upland Rice. Makariki, Cropping Season I

Treatment	Cropping Pattern				LER
	Monoculture		Intercropping		
	Maize	Upland rice	Maize	Upland rice	
	.... (t ha^{-1})...............................				
Nasa 29 + Inpago 8 (P1)		3.150	4.462	1.833	1.82
Nasa 29 + Inpago 11 (P2)		2.483	5.699	1.700	2.26
Nasa 29 + Inpago 12 (P3)		2.691	5.423	1.785	2.17
Nasa 29 + Rindang 1 (P4)		2.217	5.625	2.285	2.59
Nasa 29 + Rindang 2 (P5)		2.083	4.444	1.967	2.17
Nasa 29	3.611				
Average	3.611	2.525	5.131	1.914	2.20

This suggests that intercropping Nasa 29 corn with high-yielding upland rice varieties (Inpago 8, Inpago 11, Inpago 12, Rindang 1 and Rindang 2) can significantly enhance land productivity, making it highly suitable for dryland cultivation. This aligns with the findings of Ceunfin et al. (2017); Karimuna et al. (2019) and Saleh et al. (2020), who observed that a LER value greater than 1 indicates that monoculture systems require more land than intercropping systems. The highest LER value (2.59) was achieved with the Nasa 29 corn and Rindang 1 intercropping, followed by the Nasa 29 corn and Inpago 11 intercropping. In contrast, the lowest LER value (1.82) was recorded for the Nasa 29 corn and Inpago 8 intercropping (Table 2). This indicates that intercropping Nasa 29 corn with new high-yielding varieties of upland rice (Inpago 8, Inpago 11, Inpago 12, Rindang 1, and Rindang 2) can enhance land productivity, making it highly suitable for development on dry land. This aligns with the findings of Ceunfin et al. (2017); Karimuna et al. (2019); Saleh et al. (2020), who suggested that a Land Equivalent Ratio (LER) greater than 1 reflects a more efficient land use in intercropping compared to monoculture systems. The highest LER value (2.59) was recorded for the intercropping of Nasa 29 corn and Rindang 1, followed by the Nasa 29 corn and Inpago 11 combination, while the lowest LER value (1.82) was observed in the Nasa 29 corn and Inpago 8 intercropping.

Analysis of Farm Income and Efficiency

The analysis of farm income for intercropping patterns of corn and upland rice focused on the performance of input utilization (production costs) and output generation (yields). Production costs encompass all expenses incurred during the farming process, including the cost of production inputs and labor. Farm profits are calculated as the difference between total revenue (gross income derived from yield multiplied by the market price at harvest) and the overall production costs within the farming system. This profit represents the net income earned by farmers employing either the intercropping method of corn and upland rice or monoculture practices. By evaluating the requirements for production inputs and labor allocation, the total production costs for the intercropping system involving Nasa 29 corn and upland rice in Makariki during the first planting season of 2020 were determined. These findings are detailed in Table 3. Table 3 reveals that the average cost associated with intercropping patterns was higher (Rp. 7,517,071ha^{-1}) compared to the cost incurred under intercropping pattern treatments (Rp. 7,320,000ha^{-1}). However, the production cost for monoculture corn (Rp. 7,370,000ha^{-1}) was lower than the average expense for intercropping corn with upland rice (Rp. 9,895,077ha^{-1}). In contrast, the production cost for monoculture upland rice (Rp. 7,720,000ha^{-1}) exceeded the average expense for the intercropping pattern with corn (Rp. 5,139,065ha^{-1}).

The lower production costs for monoculture corn can be attributed to its smaller planting population (62,500 plantsha^{-1}) compared to the significantly higher population in the intercropping system (110,000 plantsha^{-1}), representing a 176% increase. Similarly, monoculture upland rice incurred higher expenses (Rp. 19,693,440ha^{-1}) than rice grown in an intercropping system with corn (Rp. 5,139,065ha^{-1}). This is because the population density for monoculture upland rice was higher (330,000 clumpsha^{-1}), an increase of 76% compared to upland rice in intercropping systems (250,000 clumpsha^{-1}). The high corn population in the intercropping pattern significantly influenced revenue (yield per hectare × selling price per kilogram) and resulted in higher average farm income. Specifically, the revenue and income were Rp. 25,653,000ha^{-1} and Rp. 15,757,923ha^{-1}, respectively, compared to monoculture corn, which generated Rp. 18,055,000 ha^{-1} in revenue and Rp. 10,686,000ha^{-1} in income (Table 3). Conversely, the lower population of upland rice in the intercropping system led to reduced average revenue and expenses of Rp. 14,929,200ha^{-1} and Rp. 9,790,135ha^{-1}, respectively, compared to monoculture upland rice, which recorded Rp. 19,693,400ha^{-1} in revenue and Rp. 10,352,867ha^{-1} in expenses.

Table 3: Analysis of income and efficiency of farm business planting pattern of intercropping Corn + Upland Rice. Makariki, MT-I

Treatment	Yield (t ha^{-1})	Price at harvest (Rpkg^{-1})	Production facility cost	Labour cost	Expense	Revenue	Income	B/C
			Rp ha^{-1}					
Monoculture								
Corn (Nasa 29)	3.611	5,000	3,770,000	3,600,000	7,370,000	18,055,000	10,685,000	1.45
Upland rice								
Inpago 8	3.160	13,000	3,420,000	3,850,000	7,270,000	24,570,000	17,300,000	2.38
Inpago 11	2.483	13,000	3,420,000	3,850,000	7,270,000	19,367,400	12,097,400	1.66
Inpago 12	2.691	13,000	3,420,000	3,850,000	7,270,000	20,989,800	13,719,800	1.89
Rindang 1	2.217	13,000	3,420,000	3,850,000	7,270,000	17,292,600	10,022,600	1.38
Rindang 2	2.083	13,000	3,420,000	3,850,000	7,270,000	16,247,400	8,977,400	1.23
Average Upland rice	2.525	13,000	3,420,000	3,850,000	7,270,000	19,683,440	10,352,867	1.71
Average Monoculture	3.068	9,000	3,595,000	3,725,000	7,320,000	18,874,220	10,518,933	1.58
Intercropping								
Corn								
Nasa 29+Inpago 8	4.462	5,000	5,963,077	3,932,000	9,895,077	22,310,000	12,414,923	1.25
Nasa 29+Inpago 11	5.699	5,000	5,963,077	3,932,000	9,895,077	28,495,000	18,599,923	1.88
Nasa 29+Inpago 12	5.423	5,000	5,963,077	3,932,000	9,895,077	17,115,000	17,219,923	1.74
Nasa 29+Rindang 1	5.625	5,000	5,963,077	3,932,000	9,895,077	28,125,000	18,229,923	1.84
Nasa 29+Rindang 2	4.444	5,000	5,963,077	3,932,000	9,895,077	22,220,000	12,324,923	1.25
Average Corn	5.131	5,000	5,963,077	3,932,000	9,895,077	25,653,000	15,757,923	1.59
Upland Rice								
Inpago 8+Nasa 29	1.833	13,000	1,975,065	3,164,000	5,139,065	14,297,400	9,158,335	1.78
Inpago 11+Nasa 29	1.700	13,000	1,975,065	3,164,000	5,139,065	13,260,000	8,120,935	1.58
Inpago 12+Nasa 29	1.785	13,000	1,975,065	3,164,000	5,139,065	13,923,000	8,783,935	1.71
Rindang 1+Nasa 29	2.285	13,000	1,975,065	3,164,000	5,139,065	17,823,000	12,683,935	2.47
Rindang 2+Nasa 29	1.967	13,000	1,975,065	3,164,000	5,139,065	15,342,600	10,203,535	1.99
Average Upland Rice	1.914	13,000	1,975,065	3,164,000	5,139,065	14,929,200	9,790,135	1.91
Average Intercropping	3.522	9,000	3,969,071	3,548,000	7,517,071	20,291,100	12,774,029	1.75

Despite this, the average farm income from intercropping patterns (Rp. 12,774,029ha^{-1}) was higher than that of monoculture planting patterns (Rp. 10,518,933ha^{-1}), as illustrated in Table 3. To evaluate the economic efficiency of the farming system, the intercropping pattern of corn and upland rice was assessed using the benefit-cost (B/C) ratio. This metric is calculated by subtracting the total production costs from the total revenue (product of yield and selling price) and then dividing the result by the total production costs. A farming system is deemed economically efficient and profitable when the B/C ratio exceeds 1. The economic efficiency of farming systems involving intercropping corn and upland rice is summarized in Table 3. The data indicate that both monoculture and intercropping patterns yield a benefit-cost (B/C) ratio greater than 1, signifying economic efficiency. Specifically, the intercropping pattern achieves a higher B/C ratio (1.75) compared to the monoculture pattern (1.58). This implies that for every Rp. 100 spent, the intercropping system generates a profit of Rp. 175, while the monoculture system yields Rp. 158 in profit.

Furthermore, upland rice, whether grown in monoculture or intercropped with corn, achieves a higher B/C ratio than corn under both monoculture and intercropping systems. Table 3 shows that monoculture upland rice has a B/C ratio of 1.71, surpassing that of monoculture corn, which has a B/C ratio of 1.45. This indicates that every Rp. 100 spent on monoculture rice returns a profit of Rp. 171, whereas monoculture corn returns Rp. 145 in profit. Similarly, in intercropping systems, both corn and upland rice maintain a B/C ratio greater than 1. The average B/C ratio for intercropped corn is 1.59, while intercropped upland rice achieves a higher value of 1.95. This means that for every Rp. 100 spent, intercropped corn yields a profit of Rp. 159 and intercropped upland rice generates a profit of Rp. 195.

The empirical evidence presented aligns with previous studies, including those by Falatehan et al. (2017); Crusciol et al. (2021); Lanamana & Supardi (2021) and Harjadi et al. (2023) which highlight the advantages of intercropping upland rice, particularly when paired with corn. A distinguishing feature of this research, however, is the finding that while the average income of upland rice farmers using intercropping systems is lower compared to those practicing monoculture, the opposite is true for corn. Farmers growing corn under intercropping patterns achieve higher average income than those employing monoculture planting systems.

Similar findings were also reported by Crusciol et al. (2021), Hairmansis et al. (2023), Rahajaharilaza et al. (2023), and Labrador et al. (2024), who stated that intercropping rice planting is more profitable in tropical areas. The net profit obtained by farmers using the intercropping planting system is often greater than that of monoculture. These advantages are associated with the efficient use of resources, particularly on dry land in tropical areas, reduced risk of crop failure and improved soil fertility through complementary interactions between different plant species. Additionally, intercropping systems often enhance biodiversity, which contributes to better pest control and ecosystem stability, further boosting economic benefits for farmers.

Conclusion

Intercropping maize and upland rice offers notable productivity benefits for maize but poses challenges for upland rice yields. Maize productivity increased significantly in the intercropping system, reaching 5.131 t/ha—a 142% improvement compared to maize monoculture (3.611 t/ha). This increase resulted from a higher plant population in the intercropping system (110,000 plants/ha) versus monoculture (62,500 plants/ha). However, maize yields remained below their maximum potential (13.7 t/ha).

In contrast, upland rice productivity in the intercropping system declined by 77% compared to monoculture. This reduction was due to a lower plant population in the intercropping system (250,000 plants/ha) than in monoculture (330,000 plants/ha), caused by wider spacing. Among upland rice varieties, Inpago 8 achieved the highest yield in both monoculture (3.150 t/ha) and intercropping (2.285 t/ha). The combination of Nasa 29 maize with Inpago 8 delivered the best overall yield, while Nasa 29 + Inpago 11 produced the lowest productivity. Maize yields in the intercropping system surpassed Maluku's regional average (5.131 t/ha vs. 3.20 t/ha), while upland rice yields in both systems remained below their potential (6–8 t/ha). Optimizing planting strategies is crucial to enhancing upland rice performance.

The intercropping system demonstrated superior land efficiency, with all combinations achieving a Land Equivalence Ratio (LER) above 1. The highest LER value (2.59) was observed with the Nasa 29 + Rindang 1 combination, while the lowest (1.82) was with Nasa 29 + Inpago 8. Intercropping optimizes resource use, evenly distributes labor, and mitigates crop failure risks, making it ideal for dryland cultivation.

Economically, intercropping maize and upland rice proved efficient, achieving a higher benefit-cost (B/C) ratio (1.75) than monoculture (1.58). Upland rice showed greater economic efficiency than maize, with upland rice monoculture recording a B/C ratio of 1.71 versus maize monoculture's 1.45. Intercropping upland rice achieved the highest B/C ratio (1.95), followed by intercropped maize (1.59). Although maize intercropping incurs higher production costs, its income gains justify the investment. Meanwhile, intercropping upland rice reduces costs but generates lower income than monoculture. Ultimately, intercropping enhances profitability, optimizes resource use, and offers a viable strategy for improving dryland farming efficiency.

Theoretical Implications

This study provides valuable theoretical insights into the implications of mixed cropping, particularly in the context of maize and upland rice. First, it highlights the resource competition theory, demonstrating that mixed cropping can increase productivity for one crop (maize) while challenging the yield of another (upland rice), indicating the need for optimized population densities.

Second, the significant Land Equivalence Ratio (LER) supports the efficiency of mixed cropping systems, showing better land use compared to monoculture. Lastly, the higher benefit-cost (B/C) ratio for intercropping emphasizes its economic potential, though maize gains more benefits than upland rice in terms of income generation. These findings contribute to the understanding of mixed cropping systems and their potential to improve productivity and economic efficiency in dryland farming.

Practical Implications

This study underscores the importance of refining crop management strategies for optimizing intercropping systems, especially for upland rice, to improve overall yields and incomes. It highlights the potential of intercropping, particularly with Nasa 29 maize and high-yielding rice varieties, as a sustainable and economically efficient strategy for dryland farming in regions like Maluku. The study also provides practical insights into economic decision-making for farmers, showing that while maize benefits significantly from intercropping, tailored strategies are needed for upland rice. Furthermore, intercropping optimizes the use of resources like labor, water, and sunlight, contributing to greater sustainability and resilience in dryland farming systems. This research offers valuable guidance for both farmers and policymakers to enhance productivity, reduce risks, and improve economic returns in dryland agriculture.

Limitations

This research has not included biological parameters in assessing the productivity of juice vehicles. To overcome this, further research needs to consider this so that the generalization of the corn and rice intercropping model becomes stronger as an answer to increasing dry land productivity. Another limitation is that the research was conducted in 2020, of course the generalization is quite limited. Future analysis will require data over time to clearly see trends in productivity development so that the resulting conclusions are more robust to generalizing the findings.

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