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Assessing Opportunities to Increase Yield and Profit in Rainfed Lowland Rice Systems in Indonesia

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Abstract: In this study, we aimed to improve rice farmers' productivity and profitability in rainfed lowlands through appropriate crop and nutrient management by closing the rice yield gap during the dry season in the rainfed lowlands of Indonesia. The Integrated Crop Management package, involving recommended practices (RP) from the Indonesian Agency for Agricultural Research and Development (IAARD), were compared to the farmers' current practices at ten farmer-participatory demonstration plots across ten provinces of Indonesia in 2019. The farmers' practices (FP) usually involved using old varieties in their remaining land and following their existing fertilizer management methods. The results indicate that improved varieties and nutrient best management practices in rice production, along with water reservoir infrastructure and information access, contribute to increasing the productivity and profitability of rice farming. The mean rice yield increased significantly with RP compared with FP by 1.9 t ha^{-1} (ranges between 1.476 to 2.344 t ha^{-1}), and net returns increased, after deducting the cost of fertilizers and machinery used for irrigation supplements, by USD 656 ha^{-1} (ranges between USD 266.1 to 867.9 ha^{-1}) per crop cycle. This represents an exploitable yield gap of 37%. Disaggregated by the wet climate of western Indonesia and eastern Indonesia's dry climate, the RP increased rice productivity by 1.8 and 2.0 t ha^{-1}, with an additional net return gain per cycle of USD 600 and 712 ha^{-1}, respectively. These results suggest that there is considerable potential to increase the rice production output from lowland rainfed rice systems by increasing cropping intensity and productivity. Here, we lay out the potential for site-specific variety and nutrient management with appropriate crop and supplemental irrigation as an ICM package, reducing the yield gap and increasing farmers' yield and income during the dry season in Indonesia's rainfed-prone areas.

Keywords: rainfed lowlands; technology innovation; productivity; net income; yield gap

1. Introduction

Traditional rice systems in Southeast Asia are often constrained by low crop yields and have the potential for sustainable intensification. Cropping intensity (CI) is defined as the number of crop cycles per year on the same piece of land [1]. During the dry season under rainfed lowland rice systems, an extra crop cycle integrating improved varieties, crop and nutrient best management practices and irrigation, has the potential for large productivity increases in rice. Indonesia's humid tropical climate allows the growing of multiple crop cycles on the same field in the same year [1,2]. Drought is a major production constraint of rainfed lowland rice grown in Indonesia [3,4]. Due to the insufficient availability of irrigation water, farmers generally plant only one rice crop in the rainy season and then the land remains fallow [5]. The uncropped fallow period represents a waste of land, and a new crop management package would be desirable in order to encourage the effective use of soil and water resources [6]. Indonesia has around 4 million ha of rainfed lowlands and upland rice areas distributed across Java, Sumatra, Kalimantan, Sulawesi, Bali, Nusa Tenggara, Maluku and Papua [7,8]. There are 2.07 million ha of rainfed rice fields, 33.8% in Java and the rest outside Java, that are grown only once a year [6]. The reason for farmers not to grow rice twice a year in rainfed lowlands is generally insufficient water during the dry season [5,9]. Supplementary irrigation from rain harvests in the form of surface water (rivers), springs and groundwater around these lands presents an opportunity to increase CI during the dry season [10,11]. The availability of sufficient water for plants will extend the planting period and expand the planting area under water availability [12,13]. About 1.4 million ha out of the 2.07 million ha of rainfed rice fields have sufficient and easily accessible water sources. This means that we can use this land to develop water reservoir infrastructure (WRI) in the form of farm reservoirs, trenches, long storage, as well as river water and shallow or deep wells as a source of irrigation for plants [14]. To date, only 0.4 million ha already have WRI [5]. In this context, Presidential decree Number-1, 2018, concerning the acceleration of small farm reservoirs and other WRI, was issued [15].

Recent research [2] has shown that meeting future rice demands by the year 2035 in existing rice areas in Indonesia would require an annual yield gain rate of 88 kg ha^{-1}, which is 2.3 times higher than historical yield gain rates over the past three decades. Along these lines, the authors in [2] have shown that CI and yields are lower in lowland rainfed versus irrigated rice. Therefore, these results suggest the considerable potential to increase the overall rice production output from lowland rainfed rice systems via increasing the CI and productivity. Providing WRI can increase CI so that rice can be grown during the dry season, whereas improved agronomic technologies including high-yield cultivars and the use of fertilizers, can achieve increased productivity [16,17].

Integrated crop management (ICM), as a recommended practice developed by the Indonesian Agency for Agricultural Research and Development (IAARD), is a crop production system that conserves or even strengthens farming sustainability, taking into account potential interactions between biology, environment and land management systems [18]. The application of ICM is based on four main principles, namely: (a) ICM is an approach that aims to manage crop, land and water resources as well as possible, (b) ICM utilizes the best agricultural technology produced by paying attention to elements of the synergistic relationship between technology components, (c) ICM takes into account the suitability of technology with the physical and socio-economic environment of farmers, and (d) ICM is participatory, which means that farmers participate in testing and selecting technology components that are appropriate to local conditions and the ability of farmers through the learning process [19]. This study aimed to improve rice farmers' productivity and profit in rainfed lowlands through appropriate crop and nutrient management by closing the rice yield gap during the dry season in Indonesia's rainfed lowlands.

2. Materials and Methods

2.1. Description of Study Area

The study covered selected Indonesian provinces engaged in rice production in rainfed lowlands in the year 2019. Figure 1 and Table 1 show the map and the farmer participatory demonstration plots' location in the ten provinces designated as study areas.

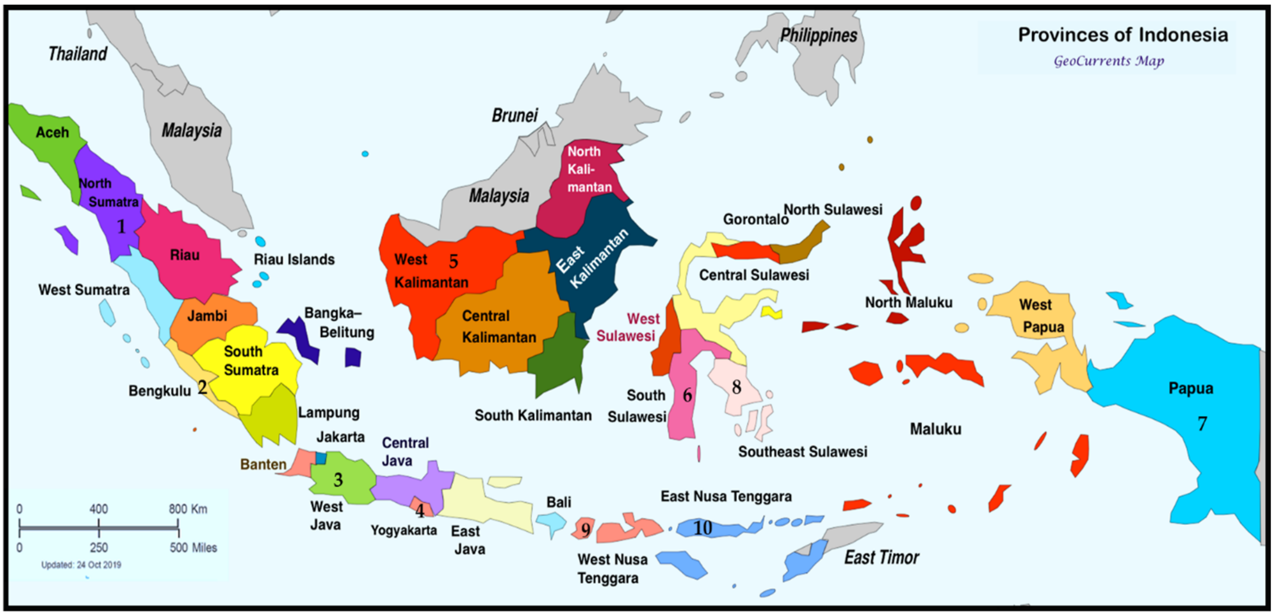

Figure 1. Map locating the ten provinces of Indonesia designated as study areas. The numbers indicate the provinces, as shown in Table 1.

Table 1. Location, number of cooperative farmers and water sources in farmer participatory demonstration plots on rainfed lowland rice in ten provinces in Indonesia, 2019.

No.	Province	District	Sub-District	Village	Farmer Group	Coordinate	Dem Area (ha)	No. of Farmers	Water Source *
					Wet Climate of Western Indonesia				
1	North Sumatra	Deli Serdang	Beringin	Serdang	Perdamean	3°36′46″; 98°51′11″	5	15	Long storage
2	Bengkulu	Seluma	Sukaraja	Air Petai	Kromo Bali	−3°53′38″; 102°22′24″	8	22	Long storage
3	West Java	Sumedang	Ujung-jaya	Kebon Cau	Sri Mekar Jaya	6°44′37″; 108°8′41″	14	35	Trench dam
4	Yogyakarta	Gunung-kidul	Playen	Logan-deng	Gemah Ripah	7°56′1″; 110°34′44″	8	66	Deep well
5	West Kali-mantan	Sanggau	Balai	Kebadu	Cadok Mayang	0°8′56″; 110°7′54″	7	20	Long storage
6	South Sulawesi	Maros	Banti-murung	Baruga	Lallo tengae II	4°96′5″; 475°11′16″	11	38	Surface water
7	Papua	Sarmi	Bonggo	Bebon Jaya	Maju Karya	−6°74′40″; 108°14′68″	5	15	Surface water

Table 1. *Cont.*

No.	Province	District	Sub-District	Village	Farmer Group	Coordinate	Dem Area (ha)	No. of Farmers	Water Source *
					Dry Climate of Eastern Indonesia				
8	Southeast Sulawesi	Konawe Selatan	Buku	Andoolo Utama	Merdi Tani I	4°17′5″; 122°12′39″	10	15	Surface water
9	West Nusa Tenggara	Lombok Tengah	Praya Barat	Penujak	Beriuk Angen	−8°46′30″; 116°13′8″	5	11	Surface water
10	East Nusa Tenggara	Manggarai Barat	Komodo	Golo Bilas	Tiwu Dangkung	−8°55′14″; 119°54′00	2	25	Long storage
	Average						7.5	26.2	

* Long storage is an elongated water reservoir that functions to store runoff and rainfall as a source of supplementary irrigation during the dry season; a trench dam (channel reservoir) is a simple irrigation technology to collect or stem the flow of water in a ditch (drainage network) to accommodate the volume of surface runoff and distribute it to surrounding agricultural land; a deep well is a pump designed for pumping water from wells with water levels more than about 7.6 m below the pump location; surface water is the use of an irrigation pump to utilize surface water sources (rivers), which have a lower water level than paddy fields, and distribute them through irrigation channels by gravity [8].

The farmer participatory demonstration plots (FPDPs) were conducted under the supervision of researchers and extensionists of the Assessment Institute of Agricultural Technology (AIAT) in each province (AIATs; http://bbp2tp.litbang.pertanian.go.id/, accessed on 11 February 2021). FPDPs in rainfed lowland rice areas were carried out on land that previously had at most CI = 1 or CI = 2. A total of ten FPDPs under different agro-climatic regions (approximately 75 hectares with 262 farmers, or an average of 0.3 ha family^{-1}) across rainfed rice fields in ten provinces in Indonesia were undertaken. The average area of each FPDP was 7.5 ha with 26.2 farmers. FPDPs were made relatively broad, involving one farmer group in each location, because farmers need to do simultaneous planting in one site to minimize pest and disease attacks and facilitate the development of water pump services. The types of WRI used at the FPDP location were long storage, trench dams, surface water and deep wells, as shown in Table 1. The primary function of FPDPs is to demonstrate the improved productivity and profitability of rice farmers during the dry season through an integrated approach consisting of new WRI, site-specific technological innovations, supporting institutions and dissemination techniques in farmers' fields.

2.2. Information Access

Information access in the form of the number of activities relating to program socialization, technical guidance and farmer field days is presented in Table 2. The socialization of the program was aimed at local government and farmer groups. Socialization of programs related to extension services facilitates the participation of local governments and farmer groups in distributing water to farmers' land and maintaining WRI in groups. Farmers attended technical guidance meetings for technology dissemination, which led to the creation of the Water User Farmers Association (Perkumpulan Petani Pemakai Air = P3A) and production input from institutional services, especially in regard to seeds, fertilizers and water pumping machines. Technical guidance meetings are meant to train farmers in the best practices related to achieving an optimum hill population of healthy plants, the use of nutrient management best practices and avoiding drought stress that could affect crop growth and yield. Farmer field days were necessary for the awareness of new technology and networking between farmers, extensionists and researchers. The success of the FPDP in the form of increasing rice productivity will convince farmers, field extensions and especially local policymakers of the production potentialities of production technologies for further wide-scale diffusion.

Table 2. The number of information access activities in the farmer participatory demonstration plots on rainfed lowland rice in ten provinces in Indonesia, dry season 2019.

No.	**Provinces**	**Program Socialization**		**Technical Guidance Meeting**		**Farmer Field Day**
		Local Government	**Farmer Group**	**Technology Dissemination**	**Institutional Services**	
		Wet climate of Western Indonesia				
1	North Sumatra	2	3	3	2	1
2	Bengkulu	3	2	3	2	1
3	West Java	2	1	5	5	1
4	Yogyakarta	2	3	3	3	1
5	West Kalimantan	2	3	3	4	1
6	South Sulawesi	1	3	2	2	1
7	Papua	3	3	3	3	1
		Dry climate of Eastern Indonesia				
8	Southeast Sulawesi	4	5	6	4	1
9	West Nusa Tenggara	1	3	2	4	1
10	East Nusa Tenggara	2	5	4	5	1
	Average	2.2	3.1	3.4	3.4	1.0

2.3. *Cropping Intensity*

We distinguished single, double and triple cropping systems with CI 1, 2 and 3, respectively. The potential land available for increasing CI in Indonesia's rainfed lowland rice areas is quite large, covering more than 1 million ha [8]. The existing rice CI in the study areas ranged from 0.79 to 1.88, with an average of 1.3 (Table 3).

Table 3. Distribution of the existing rice cropping intensity (CI) in rainfed lowlands in ten provinces of Indonesia used as study areas, 2018.

No.	**Province**	**Rainfed Area (ha)**	**Rice Planted Area (ha)**	**Cropping Intensity**
		Wet Climate of Western Indonesia		
1	North Sumatra	161,560	303,262	1.88
2	Bengkulu	23,117	33,831	1.46
3	West Java	179,647	323,918	1.80
4	Yogyakarta	9267	16,444	1.77
5	West Kalimantan	270,931	228,232	0.84
6	South Sulawesi	258,422	408,375	1.58
7	Papua	46,045	50,661	1.10
		Dry Climate of Eastern Indonesia		
8	Southeast Sulawesi	19,831	15,634	0.79
9	West Nusa Tenggara	64,491	58,432	0.91
10	East Nusa Tenggara	77,322	68,359	0.88
	Total	1,110,633	1,507,148	1.30

Data regarding the average rainfall (mm month^{-1}) and the number of rainy days month^{-1} for the last ten years (2010–2019) were collected from the study sites' climate stations. The islands of Sumatra, Kalimantan, Java and part of Sulawesi all have rainfall greater than 2000 mm year^{-1}, due to their wet climates (Figure 2). On the contrary, West and East Nusa Tenggara and Southeast Sulawesi have dry climates characterized by low annual rainfall, less than 2000 mm year^{-1}, and the lowest rainfall is in July or August. The rain falls in a short period (3–5 months), meaning that the planting period is also very short.

In Sumatra, Java and Kalimantan, July/August coincides with the dry season's onset for most areas, and the dry season continues until the end of October. In Nusa Tenggara and Southeast Sulawesi, September coincides with the dry season's onset and continues until the end of March. For rice plants, wet months are months when the average rainfall is higher than 200 mm and dry months are months when the rainfall is equal to or less than 100 mm. The 200 mm figure is used because the water demand for lowland rice, including the percolation, is close to 200 mm [20,21]. The WRI system plays a crucial role in the alleviation of drought. Established on the farm, WRI is used to harvest surplus rainfall (runoff) produced in the catchment area and in situ rainfall, as well as to store the water for supplemental irrigation of the dry season rice crop [22,23].

2.4. Recommended Practices (RPs) and Farmers' Practices (FPs)

The implementation of ICM as a recommended practice (RP) of the IAARD was carried out in FPDPs during dry seasons, when most farmers only planted small areas with rice or secondary crops (Table 4). The purpose of RP was to increase rice productivity rather than to increase CI. The ICM package designated as RP consisted of ten components: (1) using new high yielding cultivars; (2) using certified seeds with high vigor; (3) ensuring effective leveling and tillage management; (4) synchronizing seeding of the nursery; (5) establishing a sufficient plant population to ensure adequate grain-sink size; (6) applying fertilizer at the right time, and at the right amount based on site-specific nutrient management (SSNM); (7) avoiding excessive water or drought stress; (8) ensuring no yield loss due to weeds and pests; (9) harvesting at the right time; and (10) threshing at the right time [24–26].

Each cooperative farmer within an FPDP was given the recommended rice seeds and fertilizers for free, based on site-specific variety and nutrient management, as part of an ICM package of technology. Recommended newly released varieties underwent performance testing to combine high yield potential and disease resistance [27,28]. The rice crop manager (RCM) provided fertilizer recommendations at the right time and the right amount to better match the rice crop needs. Meanwhile, the RCM operated as a Rice Agro-advisory Service in Indonesia, known as Layanan Konsultasi Padi version 1.0 (http://webapps.irri.org/id/lkp/, accessed on 4 February 2021) [29]. In comparison to RP, which used various new, improved varieties (Inpari group), the farmers were accustomed to using rice varieties IR 64, Ciliwung and Ciherang, which were released before the year 2000, and local varieties in their remaining land, and followed their own fertilizer management methods (i.e., FPs). Grain yield was measured from one sampling area of 4 m × 3 m in each farmer's field at harvest and was converted to tons per hectare at 14% moisture content. Each cooperative farmer was designated as a replication within the FPDP for each province, as shown in Table 4.

Meanwhile, FP data were collected from an average of ten randomly selected farmers around the FPDP. They had the same cropping pattern and an ownership area that was relatively the same as that of the farm pool, as shown in Table 1, in each province. The mean data on grain yield of each FPDP between the farmers' current practices and the recommended practices across the ten provinces during the dry season were replicated in this study. We used a comparison between treatment means in the statistical analysis [30]. The means of the grain yield data from RP are compared to the FP data in each province. Ten provinces as replications were statistically analyzed, and Least significant difference (LSD) at a 5% level was applied to examine the significance of differences between the treatment means.

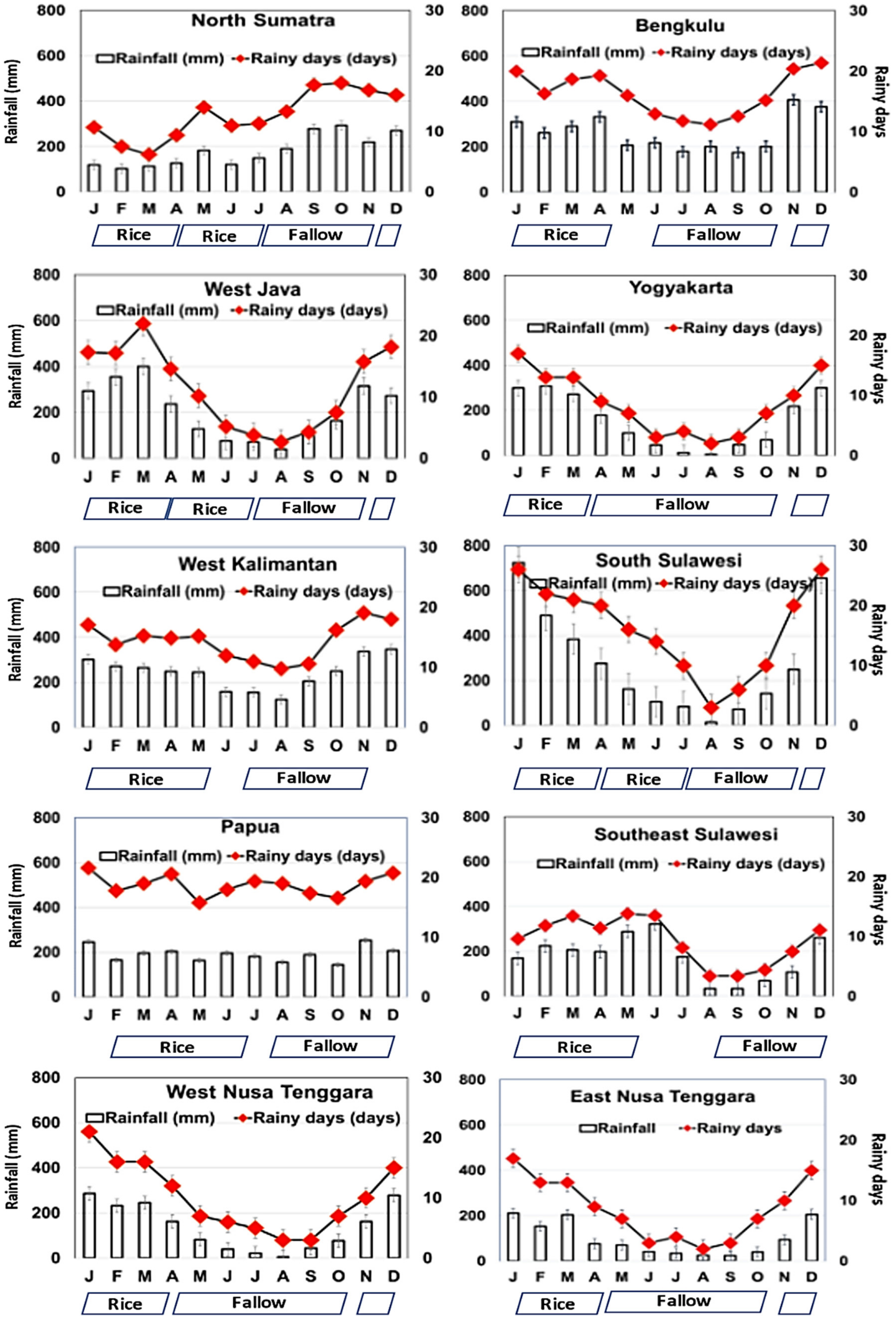

Figure 2. Rainfall (left axis, in mm^{-1}), rainy days (right axis, number of rainy days month^{-1}) and the scheme showing existing cropping sequences in rainfed lowland areas in Indonesia's ten provinces used as study sites, as shown in Table 1. Boxes show approximate crop cycle length, from sowing to harvest maturity.

Table 4. Integrated crop and nutrient management practices designated as recommended practices based on site-specific variety and nutrient management for rainfed lowland rice in ten provinces in Indonesia, dry season (DS) 2019.

No.	**Provinces**	**Crop Management**	**Number of Farmer (n)**	**Rice Variety**	**Sowing Date**	**Planting Density (m^2)**	**Fertilizer Rate (kg ha^{-1})**			
							N	**P_2O_5**	**K_2O**	**Organic Fertilizer**
				Wet climate of Western Indonesia						
1	North Sumatra	RP	15	Inpari 43	1 Jul.	25	127.5	37.5	37.5	0
		FP	10	Ciherang	22 Jul.	16	60.0	32.5	15.0	0
2	Bengkulu	RP	22	Inpari 41	25 Jun.	33	93.8	26.3	26.3	2000
		FP	10	Local var.	14 Jul.	14	37.5	15.0	15.0	0
3	West Java	RP	35	Inpari 32	5 Jul.	21	195.0	37.5	37.5	1000
		FP	10	Inpari 32	21 Jul.	16	112.5	37.5	37.5	0
4	Yogyakarta	RP	66	Inpari 19	27 Mar.	28	105.0	37.5	37.5	2000
		FP	10	IR-64	2 Apr.	21	52.5	30.0	30.0	500
5	West Kalimantan	RP	20	Inpari 32	4 Jul.	24	82.5	37.5	37.5	2000
		FP	10	Inpago 8	2 Jul.	16	60.0	15.0	15.0	500
6	South Sulawesi	RP	38	Inpari 42	2 Aug.	21	105.0	30.0	30.0	0
		FP	10	Ciherang	1 Aug.	16	90.0	15.0	15.0	500
7	Papua	RP	15	Inpari 19	4 Aug.	33	90.0	36.0	30.0	2000
		FP	10	IR 64	12 Aug.	16	22.5	18.0	15.0	0
				Dry climate of Eastern Indonesia						
8	Southeast Sulawesi	RP	15	Inpari 40	6 Sep.	25	110.0	47.5	30.0	1500
		FP	10	Ciliwung	2 Sep.	16	90.0	36.0	0	0
9	West Nusa Tenggara	RP	11	Inpari 32	5 Apr.	28	135.0	45.0	45.0	1000
		FP	10	Situbagendit	4 Apr.	16	90.0	30.0	30.0	0
10	East Nusa Tenggara	RP	25	Inpari 32	14 Apr.	21	120.0	30.0	30.0	0
		FP	10	Ciherang	11 Apr.	16	60.0	15.0	15.0	0

RP = recommended practices; FP = farmers' practices.

2.5. Yield Gap between RP and FP

The attainable yield of a rice variety is the highest yield obtained in the adaptability test activities carried out in 16 different locations in one growing season or eight of the same locations in two planting seasons (wet season and dry season). The adaptability represents the agro-ecological characteristics of the rice production center areas concerned [31]. The exploitable yield gap of a crop grown in a particular location and cropping system is defined as the difference between the yield under optimum management and the average yield achieved by farmers [32]. The exploitable yield gap is described as a percentage by dividing this value by the yield under optimum management. Agro-economic analysis based on the average yield of each FPDP revealed yield gaps between the farmers' current practices and the recommended practices across ten provinces.

Agro-economic analysis based on the partial budgets was constructed using farmers' varieties with farmers' current practices and recommended practices for increased rice productivity during the dry season across ten provinces. The purpose of the partial budget analysis was to evaluate the differences in costs and benefits among different management systems on a one-cycle basis during the dry season for rice crops. In the preparation of the partial budget analysis, not all of the costs of production were considered. Instead, only the costs that varied among the systems of management practices were taken into account [33,34]. The variable cost included fertilizer input (chemicals and organic fertilizer) and irrigation supplements in each province. The profit analysis compared expected costs and profits between the FP and RP. Revenue was calculated by multiplying the grain yield of rice crop by the farm gate price in 2019 in each province [35], whereas the change in benefit is the difference between extra profit above the total cost of RP with FP [33]. All the economic data were converted into USD using an exchange rate of USD 1 = IDR 14,250.

3. Results

3.1. Grain Yield Compared between RPs and FPs

The use of improved varieties and nutrient management best practices according to ICM guidance in rice production with WRI so that rice could be grown during the dry season in FPDPs contributed to an increase in rice farming productivity. Grain yield under RPs showed significantly higher yield per cycle than under the FPs across rainfed lowlands in ten provinces in Indonesia during the dry season (DS) in 2019 (Table 5).

Table 5. Disaggregated rice grain yield and yield increase compared between RPs and FPs in rainfed lowlands sorted by the wet climate of western Indonesia and the dry climate of eastern Indonesia, DS 2019.

No.	Province	Mean Recommended Practices (RPs)				Mean Farmers' Practices (FPs)				Yield Increase	
		RP	Std. Dev	Min	Max	FP	Std. Dev	Min	Max		
		Grain Yield at 14% m.c. (t ha^{-1})								(t ha^{-1})	(%)
		Wet Climate of Western Indonesia									
1	North Sumatra	6.797 a	0.379	5998	7341	4.453 b	0.206	4117	4782	2.344	52.64
2	Bengkulu	4.616 a	0.265	4160	5108	2.360 b	0.189	2155	2763	2.256	95.59
3	West Java	7.572 a	0.216	7028	7812	5.464 b	0.287	4908	5800	2.108	38.58
4	Yogyakarta	5.127 a	0.181	4718	5521	4.023 b	0.182	3875	4421	1.104	27.44
5	West Kalimantan	4.175 a	0.141	3990	4448	2.699 b	0.183	2432	3105	1.476	54.69
6	South Sulawesi	5.196 a	0.209	4902	5520	3.642 b	0.161	2461	3129	1.554	42.67
7	Papua	4.960 a	0.138	4830	5389	3.168 b	0.160	2890	3421	1.792	56.67
	Sub-average	5.492	0.218	5089	5877	3.687	0.195	3263	3917	1.805	52.60
		Dry Climate of Eastern Indonesia									
8	Southeast Sulawesi	5.578 a	0.148	5325	5872	3.525 b	0.163	3305	3775	2.053	58.24
9	West Nusa Tenggara	5.064 a	0.167	4902	5420	3.129 b	0.126	2927	3362	1.935	61.84
10	East Nusa Tenggara	4.608 a	0.274	4237	5005	2.461 b	0.235	2058	2685	2.147	87.24
	Sub-average	5.083	0.196	4821	5432	3.038	0.175	2763	3274	2.045	69.11
	Average	5.288	0.207	4955	5655	3.363	0.185	3013	3596	1.925	60.85

In a row, means followed by the same letter are not significantly different at $p < 0.05$.

The average yield using farmers' varieties with farmers' current practices in individual crops was 3.363 t ha^{-1}, compared with 5.288 t ha^{-1} with RP. On average, RP indicated an increase in rice productivity of 1.925 t ha^{-1} (ranging between 1.476 and 2.344 t ha^{-1}) or 60.85% (ranging between 38.58% and 95.59%) higher than FP. Under disaggregation by the wet climate of western Indonesia and the dry climate of eastern Indonesia, compared to FP, RP increased rice productivity per cycle by 1.805 and 2.045 t ha^{-1}, or 52.60% and 69.11%, respectively, during the dry season. There was a wide range of mean yield increases between FPs and RPs. The mean yield increase varied from 38.58% in West Java to 95.59% in Bengkulu during the study period. The high yield increases in RP compared to FP in Bengkulu were due to FP using local varieties with farmers' current practices compared to high-yield cultivars with RP. Similarly, in East Nusa Tenggara, this was more due to insufficient supplementary irrigation water in the FP's dry season.

3.2. Profit Analysis between RPs and FPs

Based on each treatment's average yield across ten provinces, agro-economic analysis of farmers' field demonstration plots revealed yield gaps between RPs and FPs (Table 6).

Table 6. Disaggregated profit analysis with recommended practices in rainfed lowlands sorted by the wet climate of western Indonesia and the dry climate of eastern Indonesia.

No.	Province	Yield Increased	Benefit	Additional Cost			Change in Benefit
				Fertilizers	Irrigation	Total	
		(t ha^{-1})	(USD ha^{-1})				
Wet climate of Western Indonesia							
1	North Sumatra	2.344	897.8	29.8	0	29.8	867.9
2	Bengkulu	2.256	855.0	133.0	0	133.0	722.0
3	West Java	2.108	805.3	82.8	0	82.8	722.4
4	Yogyakarta	1.104	410.7	47.7	96.8	144.6	266.1
5	West Kalimantan	1.476	574.2	62.8	0	62.8	511.4
6	South Sulawesi	1.554	536.1	85.3	−14.0	71.2	464.9
7	Papua	1.792	754.4	92.6	17.5	110.2	644.3
	Sub-average	1.805	690.5	76.3	14.3	90.6	599.9
Dry climate of Eastern Indonesia							
8	Southeast Sulawesi	2.053	763.7	−1.4	21.6	20.2	743.5
9	West Nusa Tenggara	1.935	716.0	44.2	0	44.2	671.7
10	East Nusa Tenggara	2.147	772.9	21.1	31.6	52.6	720.3
	Sub-average	2.045	750.9	21.3	17.7	39.0	711.8
	Average	1.925	720.7	48.8	16.0	64.8	655.9

Benefit = yield increase × farm gate price; additional cost = total cost of fertilizers (inorganic and organic sources) and machinery used for irrigation supplement; Change in benefit = benefit − additional cost.

Demonstration plots conducted in the farmers' fields in the rainfed lowlands of ten provinces in Indonesia indicated that there were additional net return gains of USD 655.9 ha^{-1} (ranging between USD 266.1 and 867.9 ha^{-1}) per cycle after deducting the costs of fertilizers and machinery used for irrigation when using RP compared to FP. On average, the additional net return gain per cycle during the dry season in the wet climate of western Indonesia and eastern Indonesia's dry climate was USD 599.9 and 711.8 ha^{-1}, respectively.

3.3. Yield Gap between Attanaible Yield, RPs and FPs

Herein, the attainable yield of a rice variety is defined as the highest yield obtained in the adaptability test activities, representing the agro-ecological characteristics of rice production center areas. The exploitable yield gap of a rice variety grown in a certain location is a percentage of the difference between the yield under optimum management practices and the average yield achieved by farmers. Site-specific variety and nutrient management with good crop and supplemental irrigation are considered recommended practices under optimum management. The attainable yield of improved high-yield Inpari varieties ranged from 7.8 to 10.6 t ha^{-1} (Table 7). Under disaggregation, the attainable yield of Inpari varieties was relatively higher in western Indonesia's wet climates than in the dry climate of eastern Indonesia (9.06 vs. 8.80 t ha^{-1}). The average total yield gap was 62.38%, which is lower in the wet climate of western Indonesia (59.18%) than in the dry climate of eastern Indonesia (65.58%). The average exploitable yield gap between FP and RP in rainfed lowland rice areas across ten provinces in Indonesia was observed to be 36.99%. After disaggregation, the average exploitable yield gap was lower in western Indonesia's wet climate (33.45%) than in the dry climate of eastern Indonesia (40.54%).

Table 7. Disaggregated attainable yield, total yield gap and exploitable yield gap in rainfed lowlands in the wet climate of western Indonesia and the dry climate of eastern Indonesia, DS 2019.

No.	Provinces	Variety	Attainable Yield (t ha^{-1})	Total Yield Gap (%)	Exploitable Yield Gap (%)
			Wet climate of Western Indonesia		
1	North Sumatra	Inpari 43	9.20	51.60	34.49
2	Bengkulu	Inpari 41	7.83	69.86	48.87
3	West Java	Inpari 32	8.40	34.95	27.84
4	Yogyakarta	Inpari 19	9.50	57.65	21.53
5	West Kalimantan	Inpari 32	8.40	67.87	35.35
6	South Sulawesi	Inpari 42	10.60	65.64	29.91
7	Papua	Inpari 19	9.50	66.65	36.13
	Sub-average		9.06	59.18	33.45
			Dry climate of Eastern Indonesia		
8	Southeast Sulawesi	Inpari 40	9.60	63.28	36.81
9	West Nusa Tenggara	Inpari 32	8.40	62.75	38.21
10	East Nusa Tenggara	Inpari 32	8.40	70.70	46.59
	Sub-average		8.80	65.58	40.54
	Average		8.93	62.38	36.99

4. Discussion

Rice yield in the drought-prone rainfed lowlands is constrained by the low availability of water and nutrients. The international rice research community classifies rainfed lowlands as being at a high-risk of low agricultural productivity because they are potentially threatened by drought, flooding and salinity [36,37], although the lowland rainfed environment of Indonesia is more favorable compared with that of lowland rainfed rice in other parts of Southeast Asia [4]. The results of this study show that the mean yield using improved varieties and nutrient management best practices, designated as RP, as opposed to farmers' commonly used varieties with farmers' current practices in individual crops during the dry season, was 5.288 t ha^{-1} compared with 3.363 t ha^{-1} with FP, or 60.85% higher than FP (Table 5). The technological innovations of ICM, such as site-specific variety and nutrient management, were necessary to bridge these gaps in Indonesia's rainfed lowlands. Rainfed lowland ecosystems that are physically at risk and accompanied by infestations of pests, diseases and weeds discourage farmers from applying intensive technology to these ecosystems [38]. The anticipation of risk can be pursued through plant breeding [39,40], cultivation techniques [41] and the management of plant nutrients [42,43]. The use of various new, improved varieties (the Inpari group) that are more suitable and tolerant of specific locations' pests and diseases results in higher yields than the use of the popular IR64 and Ciherang varieties, which are becoming more susceptible to major pests and diseases in Indonesia [44,45]. Nearly all rice farmers use fertilizer, but most farmers do not use the best nutrient management practices in rice production. A recent study [26] showed that many rice farmers in Indonesia apply too much N fertilizer during the early stage and too little N fertilizer at panicle initiation. The increase in yield in this study is also supported by the use of fertilizer at the right time and the right amount to better match the rice crop's needs [46,47]. Both approaches thus reduce the risks of crop failure by farmers.

The average increase in rice productivity was 1.925 t ha^{-1} (ranging between 1.476 and 2.344 t ha^{-1}) and the net return was USD 655.9 ha^{-1} (ranging between USD 266.1 and 867.9 ha^{-1}) per crop cycle as additional profit due to the use of recommended practices in farmers' fields during the dry season (Table 6). Similar findings with an increase in yield and benefit were reported by [48–50] in their study of the on-farm assessment of rainfed lowland rice. Disaggregated profit analysis per crop cycle with recommended practices in rainfed lowlands in the wet climate of western Indonesia and in eastern Indonesia's dry climates returned profits of USD 599.9 and 711.8 ha^{-1}, respectively. The additional cost expenditure for purchasing fertilizer was higher in rainfed lowlands in the western Indonesia's wet climate (76.3 vs. 21.3 USD ha^{-1}). In comparison, the additional cost of supplementary irrigation was comparable in the wet climate of western Indonesia to that in the dry climate of eastern Indonesia (17.7 vs. 14.3 USD ha^{-1}). These results are in line with the findings of [51], which show that low rainfall in dry climates causes the soil not to undergo intensive washing, meaning that the bases in the soil are quite high, the cation exchange capacity and base saturation are high and the level of soil fertility is relatively high. This is one of the advantages of dry climates compared to wet climates, where the washing is so intensive that the soil is poor in nutrients and acidic.

The values of attainable yield on high-yielding varieties used in this study ranged from 7.83 to 10.60 t ha^{-1}, as shown in Table 7. The attainable yield values are consistent with those reported by [2,52] for simulated water-limited yield potential for rainfed lowland rice in Indonesia. According to [53], the difference between simulated potential and average farmers' current practices is the total yield gap. This comprises yield-defining factors that are difficult to control, such as water supply from precipitation, soil properties, nutrients, weeds and some pests and diseases. The total yield gaps and exploitable yield gaps were higher in water-limited areas in the dry climates of eastern Indonesia.

The average yield using farmers' varieties with farmers' current practices was 3.363 t ha^{-1} compared with 5.288 t ha^{-1} with recommended practices (Table 5). This represents an exploitable yield gap of 36.99% (Table 7). The average exploitable yield gap ranged between 21.53% in Yogyakarta and 48.87% in Bengkulu, indicating that the results differed according to crop management, soil fertility status, weather conditions and non-availability of irrigation water. With the adoption of improved practices and institutional interventions, the exploitable yield gap can be reduced.

The use of farmer groups in the CI program provides an excellent forum to help farmers learn and make more effective use of extension service resources provided by AIATs and local governments [54]. Working with farmer groups provides a much wider dimension to both the knowledge and experience base, and their relationships, helping to identify or recognize excellent and poor management practices [55]. Farmers who are well informed make wise decisions, and in turn are responsible for improving farming sustainability. This emphasizes the need to educate farmers through various techniques to adopt improved agricultural production technologies to reverse this trend of wide and exploitable yield gaps. The increased use of the latest production technologies along with high-yielding varieties will reduce yield gaps. This finding is in line with the findings of [56].

On average, the exploitable yield gap between farmers' current practices and fields with good crop and nutrient management was 37%. After deducting fertilizer and irrigation supplemental costs, the increase in profit was USD 656 ha^{-1} per crop cycle in ten provinces of rainfed lowland rice in Indonesia. Overall, farmers in other regions across Indonesia have significant potential, in terms of similar biophysical, climatic and socioeconomic characteristics, to increase rice yields by adopting these improved Inpari rice varieties with best management practices. This study lays out the potential for site-specific variety and nutrient management with good crop and supplemental irrigation in reducing yield gap and increasing income during the dry season in Indonesia's rainfed-prone areas. Reducing the yield gap requires a significant acceleration to increase rice productivity growth. If Indonesia cannot achieve this acceleration, expansion of new agricultural land will be needed, with the consequences of loss of biodiversity, increased greenhouse gas emissions or a significant dependence on rice imports [57]. Closing the exploitable gap would allow Indonesia to reach near self-sufficiency in rice without massive agricultural land expansion to marginalized environments and fragile ecosystems [2].

In addition to yield increases, increasing CI may provide another promising opportunity to increase crop production [16]. Some provinces in Indonesia have a large CI gap, meaning that they can achieve some additional harvests. The potential of available land for increasing rice productivity in Indonesia's rainfed lowland areas is quite significant, as this land covers more than 1 million ha. Increasing the rice CI during the dry season will increase rice productivity in Indonesia by almost 2 million tons in each cropping cycle during the dry season and contribute to national self-sufficiency. However, this scenario is optimistic, as it assumes that water, labor and other production inputs will be available for the entire cropland to support the growth of an extra crop cycle. This is a preliminary study, and the results need to be verified with additional studies regarding changes in cropping patterns.

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