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Shallot growth and yield supported by irrigation and nitrogen application in utilizing dry land area in Mesuji, Lampung Province, Indonesia

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ABSTRACT

Lampung Province, Indonesia local government intended to extend shallot cultivation in Mesuji Regency, Lampung (-3.86, 105.43). Mesuji has 21,863.5 ha dry land area, with unproductive land of 10,325.6 ha which could be potential for growing *shallot*. However, horticulture crops such as shallot often face obstacles in dry land since dry land characterized with poor soil nutrient and limited water. The objective of this research are to analyze the effects of nitrogen fertilizer and different irrigation volumes on shallot growth and production, investigate shallot suitability to Mesuji agro-climate, and estimate shallot yield potential in Mesuji. The treatments on factorial split block were: without N, 80 kg N ha^{-1} , 160 kg N ha^{-1}, and 240 kg N ha^{-1} and the irrigation levels: 25, 50, 75 and 100% of ETc; ETc is crops evapotranspiration. The Mesuji agro-climate was evaluated using standardized precipitation index (SPI) and the yield was simulated by Aquacrop model. The results showed that the effort of shallots production with a high fresh weight of bulbs and biomass in the Mesuji area requested water at least 75% ETc and N fertilizer doses of 160 kg N ha^{-1}. The SPI indicated near normal condition was more than 65%, and drought existed in a small percentage in both places (a total of 16.9% for Brebes the centre of shallot production and 19.43% for Mesuji). The AquaCrop simulation gave a good yield estimation (simulated 19.451 ton ha^{-1} and observed 17.351 ton ha^{-1}). There is a possibility that shallot will grow well in the Mesuji area even though the quality of the shallot should be further tested.

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1. INTRODUCTION

Shallot (*Allium ascolicum* L.) is one of the Indonesian national strategic commodity. In 2021, approximately 1.94 million metric tons of shallots were produced in Indonesia, or on average 3.2 kg capita^{-1} year^{-1}; however, demand for shallots in Indonesia increases in line with the population growth trend and due to the growth of the food processing industry, with shallots as one of the ingredients (Statista, 2021). Indonesia should increase shallot production since a competitiveness study showed that it is more profitable than importing it from other countries, one of which is improving cultivation technology (Saptana et al., 2021).

The Indonesian agriculture ministry attempted to cultivate shallot in a large area in Lampung since shallot has adapted to grow in a wide range of soil and agro-climatic conditions. Shallot is cultivated in all dryland in Indonesia provinces, but with low productivity (9.67 ton ha^{-1}) since it is cultivated in various environmental and agroclimatic conditions (Fauziah et al., 2016; Sulistyaningsih et al., 2020). With strict requirement of soil and terrain, 900,000 ha in Indonesia is suitable for shallot (Conijn et al., 2017). Brebes (Central Java) is the largest shallot plantation area in Indonesia. This area contributes 18.5 percent of the national or 57 percent of production in Central Java. Water availability is limited even in the centre of production, Losari, a Brebes subdistrict, water is abundant during the rain season but scarce during the dry season (Rahayu et al., 2018). On the other hand, suitable agroclimatic and proper cultivation management shallot obtained a high productivity in Poso, Central Sulawesi (Saidah et al., 2020). The Mesuji Regency in Lampung Province of Indonesia, with an area of 2,184 Km^2 has a potential dry land of 21,863.5 ha and unproductive land of 10,325.6 ha in the form of gardens/moorlands (BPS, 2021a, 2021b). The dry land is not irrigated most of the year but still has great potential in food crops, horticulture, annual crops, and livestock, including shallot. In Lampung Province so far, dry land use for horticultural commodities is still very limited since utilizing dry land for horticultural farming often faces various obstacles, such as low soil nutrition and limited water availability. In addition, the predicted rising air temperatures due to climate change will make it increasingly difficult for horticultural crops to grow in dry land (Hilman et al., 2019). Therefore, adaptive technology is needed in response to various limiting factors of dry land and climate change.

Low fertility of the soil must be overcome by applying fertilizers as additional nutrients. NPK macronutrients in sufficient and balanced quantities are essential for shallot plants to increase productivity and yield quality since nitrogen significantly affects bulbs' production and quality. Two experiments on Indonesia's dry land regarding soil fertility were conducted in Bangli, Bali (Buda et al., 2018) and Enrekang, South Sulawesi (Suddin et al., 2021). In Bali, the results showed that increased rates of N fertilizer up to 200 kg N ha^{-1} significantly increased bulb diameter (31.03%), fresh bulb weight (48.57%), and dry weight (35.95%) of either the seeds came from true seed shallot variety or bulb-propagated shallots. Similar to that shallot cultivation in South Sulawesi showed that compound fertilizer NPK at a dose of 700–900 kg ha^{-1} resulted in high growth and yield (14.5-16.3 ton ha^{-1}). There was considerable research on N fertilizers used in shallot cultivation (Etana et al., 2019; Halvorson et al., 2002; Widiana et al., 2020).

Water resources management through irrigation technology in shallots cultivation in dry land is necessary because water scarcity is the main limiting factor that often occurs and hinders production, especially production in arid and semiarid regions (Mohammadi et al., 2010). An experiment in India showed that the variable of plant morphology, yield, and quality of shallot bulbs all showed better performance in drip irrigation system compared to surface irrigation (Bhasker et al., 2018). In Ethiopia, deficit irrigation was experimented with, revealing that the maximum yield was recorded from irrigation at 100% ET with plastic mulch (Temesgen et al., 2018). However, for water scarce area, in order to save water without decreasing the yield, farming communities can adopt a deficit irrigation level with 70% ET under plastic mulch (Rop et al., 2016).

The BMKG (Meteorology, Climatology, and Geophysics Office in Indonesia) use Standard Precipitation Index to describe drought information. SPI has been applied in Tegal, Central Java (Pramudya & Onishi, 2018), Cilacap (Balbo et al., 2019), Medan, Ambon, and Denpasar (Muharsyah, 2016). It is necessary to evaluate Mesuji's agroclimatic condition to that of Brebes for shallot production. Evaluating SPI is an effective way of analyzing alternate dry and wet weather cycles. Also, it functions as an effective way of quantifying the precipitation deficit for different time scales providing early warning of drought and assessing drought severity (Ganapathi, 2018). This study used six months of SPI since this is an indicator of agricultural drought, which links various meteorological drought characteristics to agricultural impacts.

Since water might be the limiting factor, the AquaCrop model was chosen for simulating the yield. AquaCrop is a crop growth model developed by FAO's Land and Water and is particularly well suited to conditions in which water is a crucial limiting factor in crop production. This model is widely used in simulating crops yields such as soybean (Khoshravesh et al., 2013), wheat (Mansour et al., 2020), maize (Giménez, 2019), sweet potato (Beletse et al., 2013), potato (de la Casa et al., 2013) and vegetables (Walker et al., 2013).

The objectives of this study were to investigate the effect of nitrogen fertilizer and irrigation on shallot growth and yield on dry land, evaluate Mesuji agro-climatic suitability for developing shallot, and validate the AquaCrop model in simulating shallot yield.

2. MATERIALS AND METHODS

2.1. Study sites

The experiment was conducted at BPP (Balai penyuluhan Pertanian/Agricultural Extension Center) Mesuji Lampung experimental station from January to March 2022.

2.2. Data sources

Climate data sources came from Mesuji's AAWS (Automatic Agroclimate and Weather Station) BMKG and NASA power source satellite data. Soil physical data were obtained from field soil samples analyzed in the Soil Physics Laboratory, POLINELA (Politeknik Negri Lampung/ Lampung Polytechnic College), Lampung.

2.3. Experimental design

The experimental design was a factorial split block with a fertilizer dose of N as the main plot and irrigation volume as the subplot. Four N fertilizer levels were: N0 (without N), N80 (80 kg N ha^{-1}), N160 (160 kg N ha^{-1}), and N240 (240 kg N ha^{-1}); and four irrigation levels were W25 (25% from ETc), W50 (50% from ETc), W75 (75% from ETc), and W100 (100% ETc). ETc was the crops' evapotranspiration rate.

This study used the Bima cultivar of shallot from central shallot production, Brebes, Central Java. The nitrogen used in this experiment was from urea fertilizer with an N content of 46%. It was divided into two applications: the first (50%) at 10-15 DAP (days after planting) and the second (50%) at 30-35 DAP.

2.3.1. Reference evapotranspiration

The reference evapotranspiration (ET_0) was estimated using FAO's ET calculator. Crop evapotranspiration was calculated from ET_0 x Kc (crop coefficient) (Sumarno, 2017). The irrigation was done using sprinkle irrigation. The Kc and the amount of irrigation water treatments is presented in Table 1.

Table 1. Shallot crop coefficient on each growth stage and the amount of water for the irrigation treatments

Growth Stage	Days after planting (DAP)	Crop Coefficient	Irrigation treatments			
			1 (25%) (mm day^{-1})	2 (50%) (mm day^{-1})	3 (75%) (mm day^{-1})	4 (100 %) (mm day^{-1})
Initiation stage	0 – 10 DAP	0.7	0.65	1.29	1.94	2.58
Vegetative stage	11–30 DAP	0.9	0.83	1.66	2.29	3.32
Tube development	31–45 DAP	1.2	1.11	2.21	3.32	4.43
Mature stage	46–55 DAP	1.2	1.11	2.21	3.32	4.43

Table 2. Soil physical analysis at the research site

No	Soil physical characteristics		Bulk density	Amount of water available	C/N ratio
	Texture				
1	• Sand	53,33 %	1.25 g cm^{-3}	FC 28.6%	11 %
	• Loam	13,67 %		PWP 21.17%	
	• Clay	33,00 %			

2.3.2. Statistical analysis

Statistical analysis was done using R Program https://cran.r-project.org/bin/windows/base/, and when the treatment effect was found significant, the mean difference was tested using the LSD test at $P \leq 0.05$.

2.4. Standard Precipitation Index

A comparison of Mesuji (Lampung) precipitation to that of Brebes (Central Java) was investigated using the Standard Precipitation Index (SPI) a widely accepted index for the quantification of drought. It was recommended through the Lincoln Declaration on Drought as the internationally preferred index for meteorological drought (Hayes et al., 2011). Statistically, SPI was designed to quantify the precipitation deficit for multiple time scales. SPI was calculated by taking the difference of the precipitation data from the mean on a certain time scale and dividing it by the standard deviation as Equation 1.

$$SPI = (X_{ik} - X_i)/\sigma_i \quad [1]$$

where X_{ik} is precipitation for the ith station and kth observation; σ_i standardized deviation for the ith station.

In order to calculate the SPI, a probability density function that adequately describes the precipitation data must be determined. Indonesia's precipitation usually follows the Gamma distribution. The departure from the mean is a probability indication of the severity of the wetness or drought that can be used for risk assessment. SPI is usually calculated using monthly data. Because SPI is a statistical approach, long data records provide more reliable statistics. This study calculated SPI using the Rstudio program (Source: https://rdrr.io/cran/spi/man/spi.html) from total monthly precipitation (mm) data from 2000-2020.

2.5. AquaCrop model

To estimate shallot production in Mesuji, a simulation using the FAO AquaCrop model (https://www.fao.org/aquacrop) was applied. The soil physical properties the research area are presented in Table 2. ETo and other climate files, including the maximum and minimum temperature (°C), mean humidity (%), radiation (MJ day^{-1}), and wind speed (m s^{-1}), were exported to AquaCrop and used for running the model. The soil physical characteristics from field soil samples were used to generate parameters for water available at field capacity (FC), permanent wilting point (PWP), and saturation (SAT). An irrigation file was created in AquaCrop for the crop and growing season; these were then used to run the model.

For shallot, a new crop was created using the selection of 'root and tuber crops', 'C4,' and 'transplanted' and by inserting the growing period of 55 days. Measured plant density data (20x15 cm) was used as input, giving an estimated initial crop canopy cover (CCo). The simulation with AquaCrop in this study was done following field water treatments with no soil fertility, soil salinity, or temperature stress.

Root-mean square error (RMSE) and Willot's index of agreement (d_{mod}) were used for evaluating the model. RMSE measures the differences between sample values simulated (s) by a model and the values observed (o) in the field. The lower the RMSE, the better a given model can "fit" a dataset; however, there is no predetermined threshold for "small enough RMSE." Willot's index of agreement is a normalized, dimensionless metric that tests general agreement. The index is bounded between 0 and 1; the more extensive the value is, sound, and the best possible score is 1.0.

$$RMSE = \sqrt{\frac{\sum_i^n (S_i - O_i)^2}{n}} \quad [2]$$

$$d_{mod} = 1 - \frac{\sum_i^n |S_i - \overline{O_i}|}{\sum_i^n (|O_i - \overline{O_i}| + |S_i - \overline{O_i}|)^2} \quad [3]$$

3. RESULTS

3.1. Shallot growth and yield

Shallot growth and yield were evaluated from plant height, leaves number, tubers fresh and dry weight, dry biomass weight, bulb diameter, root length, harvest index, and yield response factor. The results are presented in Tables 3, 4, 5, and 6. Table 3 reveals that for plant height, fertilizer application has a significant effect when given a dose of 80 kg ha^{-1}, after which the addition of fertilizer application has no effect on plant height both on 20 DAP and up to 40 DAP. The more the amount of fertilizer applied, the higher the number of leaves.

Table 3. Average shallot plant's height

Treatments	Average plant height (cm)			Average leaves number (strands plant^{-1})		
	20 DAP	30 DAP	40 DAP	20 DAP	30 DAP	40 DAP
Nitrogen Fertilizer						
N0	17.043b	20.747b	22.057b	11.586c	16.119c	20.133c
N80	19.133a	22.578a	23.574a	11.898c	18.104b	21.810c
N160	19.468a	22.618a	23.404a	12.892b	19.029b	23.717b
N240	20.001a	23.253a	23.721a	14.748a	21.653a	27.077a
LSD 5%	1.33 CV = 7.02%	1.01 CV = 4.5%	0.92 CV = 3.9%	0.76 CV =5.9%	1.58 CV = 8.4%	1.70 CV = 7.3%
Irrigation						
W25	16.582d	20 b	20.451c	10.988d	16.232b	20.717b
W50	18.108c	21.097b	21.915b	12.146c	18.333ab	23.294ab
W75	19.547b	23.720a	24.848a	13.359b	19.407a	24.122a
W100	21.408a	24.378a	25.543a	14.631a	20.933a	24.604a
LSD 5%	0.70 CV = 3.72%	1.13 CV = 5.06%	1.41 CV = 6.1%	0.97 CV = 7.6%	3.12 CV = 16.7%	2.63 CV = 11.3%

Remarks: means within a column followed by the same letter (s) are not significantly different at a 5% probability

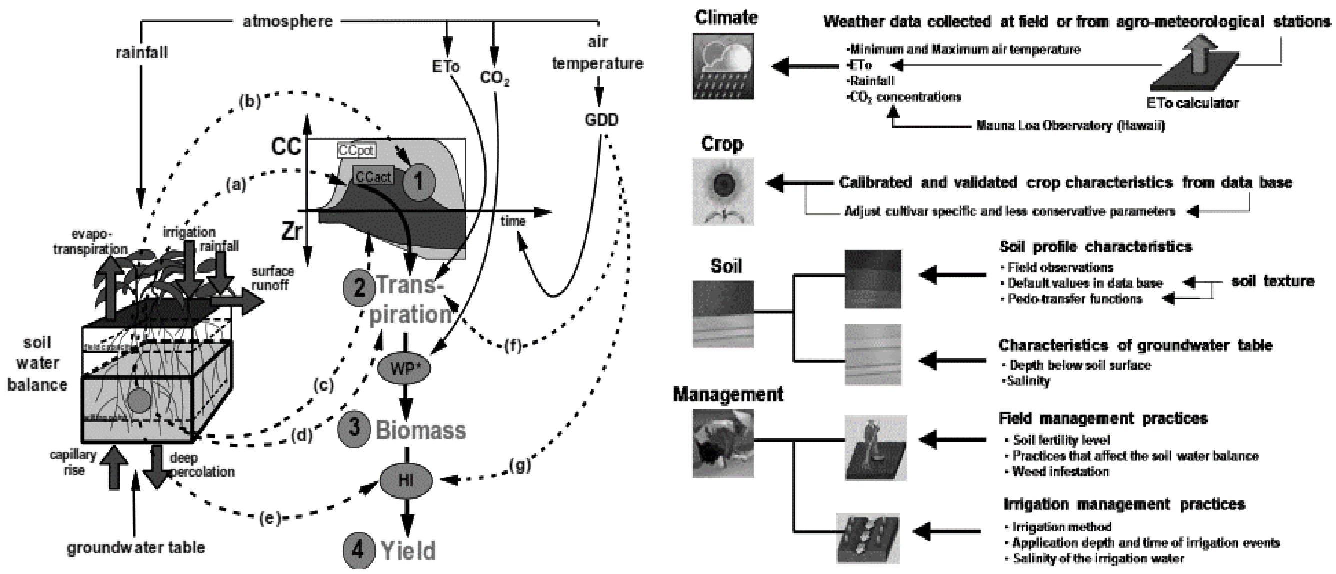

Figure 1. Description of AquaCrop model and data requirements

Providing irrigation water at the beginning of planting had a significant effect; the highest crop was achieved at W100, meaning there was no water shortage. In the following DAP, irrigation of 75% of ETc was enough to produce a significant plant height. For the number of leaves at the beginning of growth, each increase in water feeding provided an increasing number of leaves. However, in the following DAP, the provision of water of 50% ETc was enough, and the subsequent increase in irrigation no longer raised the number of leaves. Table 4 reveals that without N (N0) and for fertilizing N80, shallot's dry weights were best produced at 75% and 100% ETc and worst at the irrigation of 25% ETc. The use of N160 and N240 fertilizers with 100% ETc Irrigation (W100) gave dry weights equally well; the best yield of dry tubers, obtained with N160 fertilizer and 100% ETc irrigation (W100), was 15.88 g plant^{-1}.

The shallot dry weight of 13.9 g plant^{-1} at 75% ETc irrigation (W75) and N160 fertilizer was not significantly different with 100% ETc irrigation with N160 and N240 fertilizers 15.88 and 12.65 g plant^{-1}, respectively. N fertilization of 0, 80, 160, and 240 kg ha^{-1} and full irrigation (W100) resulted in the best fresh tuber biomass of 12.4; 13,9; 19,7; and 17.7 g plant^{-1}, respectively. These results show that using N160 fertilizer and full irrigation was enough to produce dry shallot biomass of 19.7 g plant^{-1}; adding fertilizer to N240 did not significantly increase biomass (17.66 g plant^{-1}).

Table 4. Interaction of irrigation and fertilizer on tubers fresh weight (g plant^{-1}) and fresh biomass weight (g plant^{-1})

Treatments	Irrigation				Irrigation			
	Average dry weight (g plant^{-1})				Biomass dry weight (g plant^{-1})			
Nitrogen Fertilizer	W25	W50	W75	W100	W25	W50	W75	W100
N0	6.41^{Cc}	8.13^{Cb}	10.360^{Ca}	9.56^{Ca}	6.356^{Cd}	8.31^{Cc}	10.83^{Db}	12.39^{Da}
N80	7.75^{Bc}	9.10^{BCb}	12.063^{Ba}	12.40^{Ba}	10.20^{Bb}	12.63^{Ba}	13.37^{Ca}	13.90^{Ca}
N160	10.16^{Ac}	10.11^{ABc}	13.886^{Ab}	15.88^{Aa}	12.30^{Ac}	12.28^{Bc}	14.95^{Bb}	19.73^{Aa}
N240	10.69^{Ac}	11.04^{Ac}	12.650^{Bb}	14.97^{Aa}	12.08^{Ac}	14.45^{Ab}	16.45^{Aa}	17.66^{Ba}
	Interaction CV = 5.68%				Interaction CV = 5.84%			
	LSD = 1.06				LSD = 1.30			

Remarks: means within a column followed by the same letter (s) are not significantly different at a 5% probability

Table 5. Average shallot bulb diameter, root length, tubers dry weight, and biomass dry weight

Treatments	average shallot bulb diameter (cm)	average shallot root length 55 DAP (cm)	average tubers dry weight (g tuber^{-1})	average biomass dry weight (g plant^{-1})
Nitrogen Fertilizer				
N0	11.760^{b}	23.708	0.280b	2.403b
N80	12.899^{ab}	21.767	0.292b	2.797b
N160	13.448^{a}	21.908	0.452a	3.914a
N240	13.682^{a}	24.958	0.512a	4.668a
LSD 5%	1.29	ns	0.06	0.24
	CV = 19.98 %		CV = 5.96 %	CV = 12.17 %
Irrigation				
W25	11.688^{b}	24.958^{a}	0.354b	3.143b
W50	11.902^{b}	25.808^{a}	0.339b	2.907b
W75	13.819^{a}	21.733^{b}	0.337b	3.464ab
W100	14.379^{a}	19.842^{b}	0.499a	4.115a
LSD 5%	0.71	2.72	0.06	0.19
	CV = 11.04 %	CV = 11.81 %	CV = 6.64 %	CV = 9.41 %

Remarks: means within a column followed by the same letter(s) are not significantly different at a 5% probability

Table 6. Harvest index and yield response factor

Treatments	Harvest Index	Yield Response Factor (ky)
Nitrogen Fertilizer		
N0	0.599^{b}	0.821^{a}
N80	0.684^{b}	0.827^{a}
N160	0.615^{b}	0.886^{a}
N240	0.642^{ab}	0.749^{a}
LSD 5%	0.05	0.14
CV	8.03%	14.35%
Irrigation		
W25	0.536^{c}	0.620^{c}
W50	0.611^{b}	0.776^{b}
W75	0.690^{b}	1.065^{a}
W100	0.701^{a}	
LSD 5%	0.05	0.10
CV	8.04	11.02

Remarks: means within a column followed by the same letter (s) are not significantly different at a 5% probability

Table 5 shows that the application of N 160 kg ha^{-1} gave a significant difference in the average shallot bulb diameter compared to without fertilizer. In contrast, the fertilizer application did not significantly affect the root length at the end of the growth stage. For average tubers fresh weight/plant, the application of 160 kg ha^{-1} fertilizer gave the highest biomass (51.167 g plant^{-1}). Irrigation water of 75% ETc had a significant effect on the average shallot bulb diameter as well as on the root length. For the average tuber fresh weight and individual tuber fresh weight, the results were significant only at the irrigation of 100% ETc. Water stress should be avoided during the bulbs development, it is better only a small water stress throughout crop season (Zheng et al., 2013).

Table 6 shows the harvest index, which is the ratio between the dry weight of bulbs and biomass. Fertilizer addition did not make a significant difference, but the irrigation water did. The more water feeding, the harvest index increased, which meant that the average dry weight of bulbs increased. The fertilizer application did not significantly affect the yield response factor (ky). However, the increase in fertilizer application made the yield response factor decrease, which means that with fertilizers, the crops were more tolerant to water deficit. Meanwhile, the provision of irrigation significantly affected the yield response factor.

Irrigation application of 75% from ET resulted in ky > 1 is a critical point because if the water is reduced, it will vastly reduce the yield. Reduced irrigation application to W50 or W25 significantly lowered the ky to < 1 interpreted as the shallot yield did not respond more to reduced water.

Table 7. Standardized Precipitation Index values (six months) from precipitation data 2000-2020

Characteristic	SPI Indicators	Brebes		Mesuji	
		No of events	Percentage	No of events	Percentage
Extremely Wet	>2.0	7	2.83	5	2.02
Very Wet	1.50 to 1.99	12	4.86	9	3.64
Moderately Wet	1.00 to 1.49	17	6.88	24	9.72
Near Normal	0 to 0.99	171	69.23	161	65.18
Moderately Dry	0 to -0.99	17	6.88	32	12.96
Severely Dry	-1 to -1.49	19	7.69	9	3.64
Extremely Dry	>-2.00	4	1.62	7	2.83

3.2. The Standard Precipitation Index

The Standard Precipitation Indices of Mesuji and Brebes are presented in Figure 2; the wet and dry events in those locations are compared in Table 7. Figure 2 shows that the SPI pattern between Mesuji and Brebes was similar. Table 7 showed that in both places, the SPI indicated that more than 65% of precipitation characteristic was in near normal conditions; however, even in smaller percentages (a total of 16.9% for Brebes and 19.43% for Mesuji), both areas had experienced dry conditions.

3.3 Simulating shallot yield using the AquaCrop model

The climate, crop characteristics, and soil characteristics for shallot cultivation in Mesuji that were used for yield simulation using the AquaCrop model are presented in Figure 3; the yield simulation is presented in Figure 4. Mesuji's climate during the field experiment was expressed with average RH 87.42%, total rainfall 799.43 mm, average Tmax 28.3 °C and Tmin 24.3 °C, average net radiation 17.08 MJ m^{-1}, wind speed 1.62 m s^{-1} and average standard evapotranspiration 5.1 mm day^{-1}. With a planting distance of 20 x 15 cm, the initial canopy cover was 0.5. The soil texture was sandy loam with a field capacity of 45 % (v/v), and the permanent wilting point was 20.9 % (v/v).

Table 8 shows that the amount of fertilizer did not significantly affect canopy cover at 30 DAP and 40 DAP. Increasing irrigation from 25% ETc to 50% ETc significantly increased the canopy cover. However, more water than 50% ETc did not significantly increase the canopy cover. Therefore, for the simulation, the initial canopy cover was calculated once. Based on a planting distance of 20x15 cm, the rest of the DAP used the same percentage (assumed 5%) that shallot has a moderate canopy cover increase with 62.6% maximum coverage (Table 9). Table 9 describes the calibration at the end of planting days (55 days) and growth stage 4 (yield formation and ripening). The temperature range for shallot growth was 10 – 30 C; the accumulation growing degree days was 906.6. The crop coefficient for transpiration of 0.77 made the maximum total crop transpiration 4.3 mm day^{-1} and maximum irrigation water (100% ETc) 4.43 mm day^{-1} (Table 1).

Crop water productivity (kg m^{-3}) expresses the amount of marketable product (shallot bulb) to the amount of water needed to produce the product. The water used for crop production is referred to as crop evapotranspiration. The Harvest index is the product's weight divided by the above-ground biomass weight. Table 6, the average harvest index is 0.636, while the model gave the harvest index 0.7. The fresh yield was 10.81 (W25), 17.03 (W50), 17.35, and 13.65 (W100) ton ha^{-1}. The model gave an estimation of 11.38 (W25), 14.18 (W50), 16.76 (W75), and 19.45 (W100) ton ha^{-1}. An example of the model product simulation for W100 is shown in Figure 4.

The RMSE and Willot's index of the agreement were 1.54 and 0.97, respectively. Indeed, there was a difference between the model and the observed data; In contrast, from Willot's index of agreement value, the AquaCrop model gave a high agreement with field observation data (Table 10)

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Table 8. Average canopy cover from the field as the main crop characteristic of the AquaCrop model

Treatments	Canopy cover (%)	
	30 DAP	40 DAP
0 kg N ha^{-1} (N0)	20.885^a	33.953^a
80 kg N ha^{-1} (N80)	22.943^a	34.959^a
160 kg N ha^{-1} (N160)	24.488^a	36.986^a
240 kg N ha^{-1} (N240)	22.700^a	36.859^a
LSD 5%	3.73	5.54
	CV = 16.43%	CV = 12.88%
25% ETc (W25)	17.904^b	29.063^b
50% ETc (W50)	23.853^a	36.578^a
75% ETc (W75)	26.222^a	40.228^a
100% ETc (W100)	23.037^a	36.889^a
LSD 5%	4.53	6.55
	CV = 19.93%	CV = 18.10%

Remarks: means within a column followed by the same letter (s) are not significantly different at a 5% probability

Table 9. AquaCrop model parameters, the simulation, and observation results on different water availability

No	Parameter	Parameter description	Results from AquaCrop	Results from field
1	Year	Year of planting		1
2	DAP	Days after planting (days)		55 days
3	Stage	Yield formation and ripening		4
4	GD	growing degrees (heat unit)		906.6
5	Z	Effective rooting depth (mm)	40	W25 24.958 W50 25.808 W75 21.733 W100 19.842 Table 5
6	CC	Green total canopy cover of the crop (%)	62.6	W25 29.063 W50 36.578 W75 40.228 W100 36.889 Table 8
7	Kc (Tr)	Crop coefficient for transpiration	0.77	W25 0.7 W50 0.9 W75 1.2 W100 1.2 Table 1 from the literature
8	Trx	Maximum total transpiration of crops (mm)	4.3	W 25 2.58 W50 3.32 W75 4.43 W100 4.43 Table 1 maximum irrigation
9	Biomass	Total above-ground dry biomass (ton ha^{-1})	4.061; 5.061; 5.981; 6.944	W25 4.129 w50 4.636 W75 6.576 W 100 5.886 Table 4 average biomass converted to ton ha^{-1}
10	HI	Harvest Index	0.7	W25 0.536 W50 0.611 W75 0.690 W100 0.701 Table 6
11	Y(dry)	Dry crop yield (ton ha^{-1})	2.844; 3.544; 4.19; 4.863	W25 2.917 W50 3.198 W75 4.079 W100 4.401 Table 4 dry yield converted to ton ha^{-1}
12	Y(fresh)	Fresh crop yield (ton ha^{-1})	11.376; 14.175; 16.759; 19.451	W25 10.810 W50 17.032 W75 17.351 W100 13.649 Table 5 fresh weight converted to ton ha^{-1}
13	WP et	Water productivity for yield part (kg m^{-3})	0.94; 1.17; 1.38; 1.6	W25 1.901 W50 1.041 W75 0.918 W100 0.723 Table 1 and Table 4 converted to kg m^{-3}

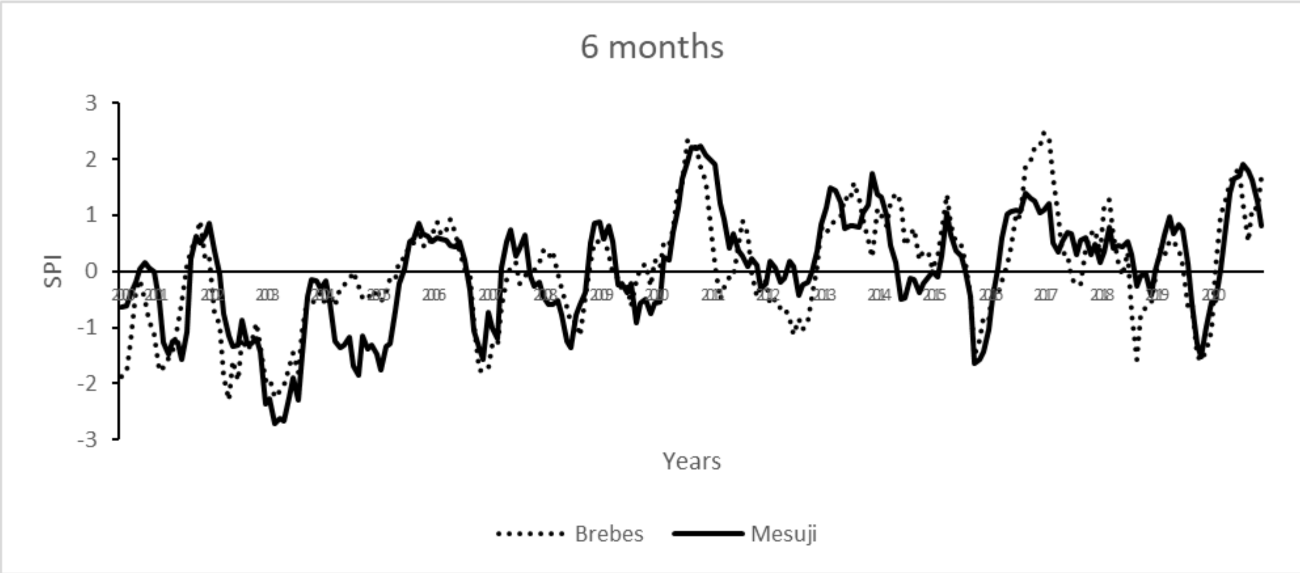

Figure 2. Standardized Precipitation indices of Mesuji (research area) and Brebes (central producers)

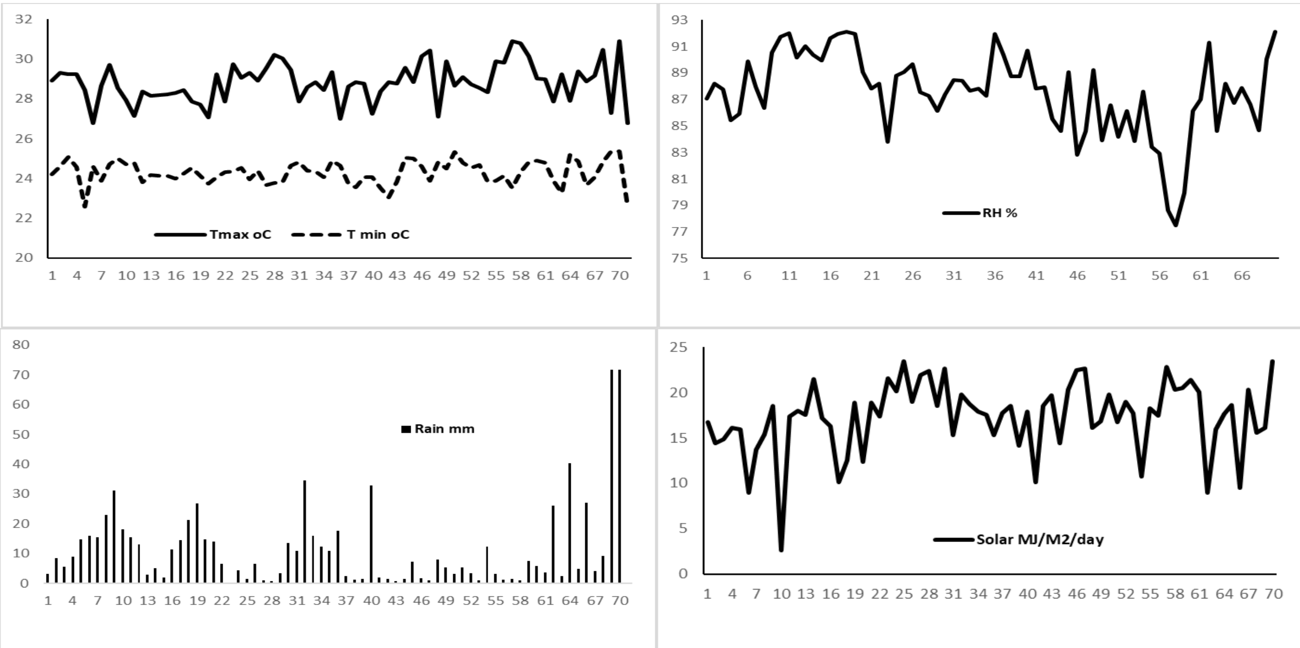

Figure 3. Mesuji's primary climate data (rainfall, air temperature, and evapotranspiration) as used for inputs to the AquaCrop model

4. DISCUSSION

This field study found that shallot in the Mesuji area grows well and produced the best dry weight of shallot planting bulbs and biomass in water availability of 75%-100% ETc and N fertilizers at 160 dan 240 kg N ha^{-1}. The SPI showed that Mesuji dominated with normal rainfall events (65%) and short dry events (19%). During normal events, water will not be a problem; however, shallot prefers dry conditions with enough soil moisture. Therefore, irrigation is essential, and to save water in the dry season, 75% of the evapotranspiration rate will be adequate for good yields. Integrate the climate with crops characteristic of shallot, soil physic of Mesuji, and irrigation management to simulate the yields are conducted through the AquaCrop model. Even though the simulated yields did not give consistent results with the field observations following the irrigation treatments, the yield both simulated and observed was above 10 tons ha^{-1}, which was compatible with national shallot production.

Nitrogen fertilizer is essential for all crop growth since nitrogen is the major component of chlorophyll for the photosynthesis process. Shallot root system is shallow and unbranched that it slows in extracting nutrients, therefore, additional fertilizers, including N will be a benefit for shallot growth. From the study, applying 100 kg N ha^{-1} and P at 70 kg ha^{-1} P_2O_5 is promising for high-quality onion seed yield (Limeneh et al., 2020). Research on the fertilizer needs of shallot has been done in various combinations and doses: Nitrogen plus phosphorus (Abdissa et al., 2011; Rizk et al., 2012), Nitrogen and Potassium (Manna et al., 2017); Nitrogen effects under different irrigation system (Halvorson et al., 2008). In general, the results of those studies revealed that nitrogen fertilizer application is an important application on the growth, yield, and quality of onions. In Ethiopia, a country that produces shallot, a low yield of onion is reported due to low soil fertility combined with an inappropriate fertilizer rate. Another research in the same country showed that using 150 kg N ha^{-1} and plant spacing of 20 cm increased bulb diameter and weight that eventually increased the yield by 26% over the control (Biru, 2015; Tesfa et al., 2015).

Water helps activate and decompose the fertilizer, then release the nutrient from the fertilizer. However, overwatering can cause the fertilizer to washed-out. For water needs, rainfall is a good source of water, but even though shallot has high adaptability, it can be grown under a wide range of climates, from temperate to tropical; shallot grows optimally in dry climates. The plant is prone to rainfall, high rain intensity, and foggy weather (Pustaka, 2017). As long as irrigation facilities are available to moist the soil, dry land is suitable for growing shallot. Save water in a dry area; most of the research in the area of water requirement for shallot was related to deficit irrigation, a strategy to save water. Even though shallot prefers to be watered at 100 % of its evapotranspiration (ET) rate, research showed 20% water stress (80% ET) saved 11 % of irrigation water without significantly affecting yields (Rop, Kipkorir, and Tarragon, 2016), while other results showed 25% water stress (Abdelkhalik et al., 2019; Dirirsa et al., 2017; Tolossa, 2021). Research in Turkey found that applied deficit irrigation should consider the growth phase. Onion needs adequate soil water the entire growing season especially in the yield formation period but is relatively insensitive in the vegetative and ripening periods (Kadayifci et al., 2005). Deficit irrigation has also been applied in Indonesia shallot field and resulted in the shallot growing well in 25% water stress (75% of the ET) (Fauziah et al., 2016) 50 % ET with plastic mulch and 1.00 Eo without mulching (Zuliati et al., 2020). This research found that 75% of the ET rate is adequate for shallot to grow well and produce a good yield.

This research showed that water adequacy affected crop vegetative variables; at the growth phase, up to 40 DAP (days after planting), shallots required sufficient water, at least available for 75% ETc. In addition to water availability, applying N fertilizers resulted in a higher plant than without N application. Likewise, on the number of leaves variable at 20-40 DAP, the more N fertilizer applied, the more leaves were produced. It is interesting to observe that water should be available at the early growth stage because sufficient water is required to dissolve the applied N fertilizer to make it available to plants, especially for leaf formation (Table 3). The additional N was required since the field has a low C/N ratio (11, see Table 2) which means that N was available, but N quickly lost since there was little carbon to compose the soil materials. Generally, a C/N ratio of 18 is suitable for adequate growth and treatment efficiency. This research showed that 160 kg ha^{-1} N fertilizers were adequate for good vegetative growth.

In the generative phase, an interaction occurred between water needs and N fertilizer application (Table 4). Water availability of 75%-100% ETc and N fertilizers at 160 dan 240 kg N ha^{-1} produced the best dry weight of shallot planting bulbs and biomass. For the cultivation of shallots in the Mesuji area, water availability of at least 75% ETc and N fertilizer doses of 160 kg N ha^{-1} was enough to produce a high dry weight of bulbs and biomass. In Table 5, both irrigation and applying N fertilizer increased the diameter of the bulbs. On the contrary, the sufficient the water, the shorter the length of the onion roots. Climate and environmental factors especially soil are the essential factors in root expansion. Since roots mainly take up water and nutrients from the upper layer, the root will develop a good root system in the upper layer. When water is available only in the deeper layer, root cells will elongate to reach the water (Zhang et al., 2019). Water availability (75%-100% ETc) and dissolved N (160 -240 kg N ha^{-1}) fertilizer were allocated more for tuber enlargement but not for root elongation. Sufficient water availability made it unnecessary for the roots to extend to reach the water. Further, the increased diameter of the tubers directly increased the dry weight of fresh tubers. The absorbed element N led to an increased formation of dry matter in tubers through the formation and division of cells.

Pérez Ortolá and Knox (2015) confirmed that onion's seasonal water requirements are highly variable depending on the location, agroclimatic characteristics, and growth stage since the crop coefficients (Kc) of shallot range from 0.4 to 0.7 (initial stage), 0.85 to 1.05 (middle development) and 0.6 to 0.75 (final stage). An experiment in Ethiopia showed that the maximum yield was obtained in the full-irrigation treatment. When water deficit happened at the first and fourth growth stages, yields are not significantly different from the optimum application. However, optimum (full) irrigation remain the best application to reach maximum yields (Bekele & Tilahun, 2007). An experiment with four treatments based on different ratios of irrigation water to cumulative open space evaporation rate, resulted that the best yields were observed from T3 (1.0) and T4 (1.2 in ratio), which produced higher percentage of bulbs with the largest diameter. Irrigation water use efficiency and water use efficiency were both highest in T2; therefore, in water limited situation, using micro-sprinkle irrigation, T2 (0.8) was an appropriate irrigation level for onion production (Kumar et al., 2007). Most research showed that water stress should be avoided at any stage of reproductive shallot growth, since it significantly reduced seed yield, and its effect was variable depending on the plant growth stage. Bolting, followed by anthesis, was the most sensitive growth stage (El Balla et al., 2013).

Table 10. Statistical data for calculations of RMSE and Willot's index of agreement

No	Variable		Observation O	Simulation S	(S-O)^2	$O_i - \bar{O}_t$ a	$S_i - \bar{O}_t$ b	(a+b)^2
1	rooting depth		2.300	4.000	2.890	3.164	1.464	21.414
2	canopy cover		0.360	0.630	0.073	5.104	4.834	98.754
3	Crop coefficient		1.000	0.770	0.053	4.464	4.694	83.860
4	total transpiration		3.700	4.300	0.360	1.764	1.164	8.570
5	dry biomass	W25	4.129	4.061	0.005	1.335	1.403	7.494
		W50	4.636	5.061	0.181	0.828	0.403	1.514
		W75	6.576	5.981	0.354	1.112	0.517	2.655
		W100	5.886	6.944	1.119	0.422	1.480	3.619
6	Harvest Index		0.640	0.700	0.004	4.824	4.764	91.921
7	Dry crop yield	W25	2.917	2.844	0.005	2.547	2.620	26.693
		W50	3.198	3.544	0.120	2.266	1.920	17.519
		W75	4.079	4.190	0.012	1.385	1.274	7.068
		W100	4.401	4.863	0.213	1.063	0.601	2.767
8	Fresh crop yield	W25	10.810	11.376	0.320	5.346	5.912	126.753
		W50	17.032	14.175	8.162	11.568	8.711	411.257
		W75	17.351	16.759	0.350	11.887	11.295	537.427
		W100	13.649	19.451	33.663	8.185	13.987	491.619
9	Water productivity	W25	1.901	0.940	0.924	3.563	4.524	65.392
		W50	1.041	1.170	0.017	4.423	4.294	75.978
		W75	0.918	1.380	0.213	4.546	4.084	74.469
		W100	0.723	1.600	0.769	4.741	3.864	74.038

Remarks: $O_i - \bar{O}_t$ (a) subtract observation mean from observation ith ; $S_i - \bar{O}_t$ (b) subtract observation mean from simulation ith value

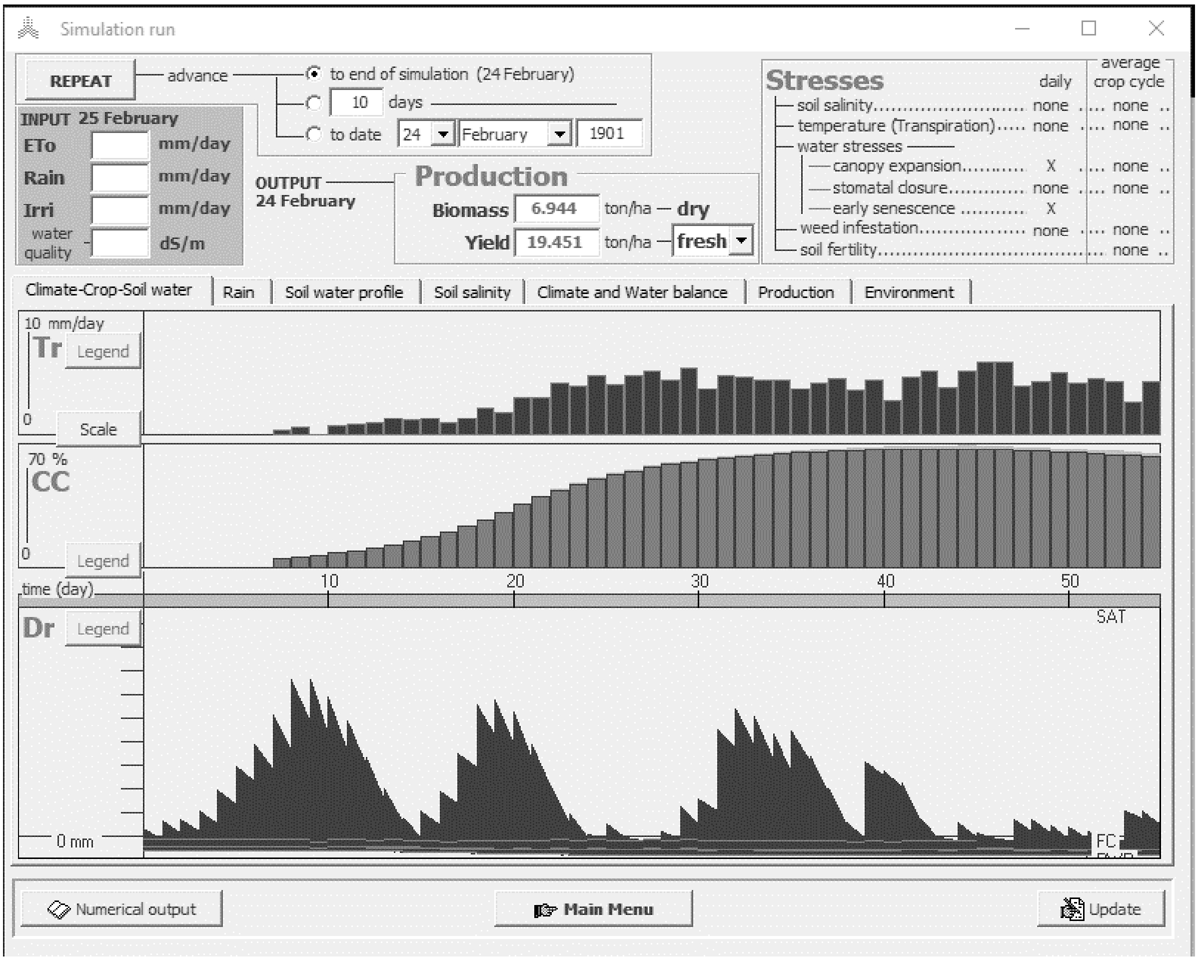

Figure 4. AquaCrop simulation for prospect shallot yield in Mesuji, Lampung

The harvest index and yield response factor are two variables that connected yield and water uses. The Harvest index is the ratio of total bulb dry weight to the total biomass dry weight expressed in percentage. The analysis of variance indicated that the harvest index was significantly influenced by the amount of irrigation water but not by N fertilizer applications, as also stated by Tolossa (2021), Biswas et al. (2003) that irrigation depth treatments is the main factor that influenced the harvest index. Another variable that connected yield and water use is the yield response factor. The yield response factor (ky) is a simple equation where relative yield reduction is related to the corresponding relative evapotranspiration reduction; it indicates the sensitivity of the crop to soil moisture deficit. When ky >1, crop response is very sensitive to water deficit, yield reduces significantly when water use is reduced; ky <1, crop is more tolerant to water deficit, means less proportional reductions in yield with water use reduction, and when ky=1, than yield reduction is directly proportional to reduced water use (Enchalew et al., 2016; Smith & Steduto, 2012). In N fertilizer application, ky ranged from 0.749-0.821, which means that even when the fertilizer requirement has been met, the water requirement should be fulfilled. If no fertilizers are applied, then lack of water should be strongly avoided, while with fertilizers applied, crops will be less sensitive to water stress. Ky in water requirement was 0.620, 0.776, and 1.065, following 25% ETc, 50% ETc, and 75% ETc, respectively. In all results, irrigation with 75% ETc application was a limit, below that, yield losses are intolerable. This result supported the results from water deficit research as mentioned above.

Shallot prefers dry climates, so additional information about meteorological drought information will be beneficial to this study. The SPI has also been used for drought monitoring in many countries with good results. In China, SPI was used for drought classification (Zuo et al., 2022). In Southern Italy, the reduction in SPI values showed a tendency toward drier conditions that were not persistent but depended on the period examined (Gabriele et al., 2013). A similar result was found in Andhra Pradesh state, India. SPI underestimated the intensity of dryness and wetness when the rainfall was very low or very high (Naresh Kumar et al., 2009). On the other hand, drought analysis in Turkey showed that precipitation analysis was in parallel with drought analysis (Güner Bacanli, 2017). From the SPI analysis with data from 2000 to 2020, the Mesuji area (Table 7) is dominated by the normal index (65.18 %) followed by the total dry index (19.43%), compared with Brebes (Normal, 69.23% and dry index 16.19%). The SPI suggested that Mesuji is drier than Brebes. However, for a tropical area, rainfall is determined by many complicated factors. BMKG stated in its regular publication https://www.bmkg.go.id/berita/?p=the-standardized-precipitation-index in the year 2022 Mesuji only had one month with a negative index (dry events) on February 2022, while Brebes had five months with negative index (January to April and September 2022). In 2022 Sumatra experienced a wet season in all months that may not be favorable for shallot cultivation. During this research, total rainfall from January to March 2022 was 799.43 mm, considered average, and the solar radiation 17.08 MJ m^{-1} resulted in an evapotranspiration rate of 5.1 mm day^{-1} which is common in Lampung. The precipitation index is only partially proper for determining particular crops' site suitability.

Combine all factors that determine shallot growth and yield (climate, crops, soil, management, including irrigation) could be evaluated through the AquaCrop model (Fig. 1) The climate data, which gave an evapotranspiration rate of 5.1 mm day^{-1}, was a reasonable value for Lampung; however, the crop coefficient factor, Kc, was lower on the model even though the Kc used in this study was based on the literature. The amount of water in the model is expressed by percentages, not actual amount of water (mm); this resulted in lower crop water use and increased water productivity value. This model used crop canopy as the important crop factor, estimated from plant spacing (20 x 15 cm). It gave the initial crop canopy of 62.6% contrast that on the field maximum crop canopy was about 40%. The shallot canopy shape was upright, and the leaves' layout did not overshadow. A technique for accurate canopy cover for a crop like a shallot is needed, and understanding the model structure and data requirement should be improved for future research. Even though not all data from the fields matched with variable on the model, the AquaCrop model gave a fair simulation for shallot yield in Mesuji. The model simulation resulted that yield are 11.376(W25), 14.175(W50), 16.759(W75), and 19.451 (W100) ton ha^{-1}, while the yield from field observation results were 10.810 (W25), 17.032 (W50), 17.351 (W75) and 13.649 (W100) ton ha^{-1}. In a similar study in Central Kalimantan, Indonesia, using the Bima cultivar on quartz sandy soil, with regular watering and added organic fertilizer to N 160 kg ha^{-1} resulted in a fresh yield of 10.11 g/tuber and production of 19.14 ton ha^{-1} (Firmansyah & Bhermana, 2019) higher than this study (maximum simulated is 19.451 ton ha^{-1} and maximum observed is 17.351 ton ha^{-1}). The FAO reported that world shallot production is 17.296 ton ha^{-1} (FAOSTAT, 2021). AquaCrop required detailed field data that should be fulfilled in future research.

5. CONCLUSIONS

Based on this research finding, it is concluded that developing shallot plantations in the Mesuji area, Lampung is possible with the caution that irrigation facilities should be provided to maintain a water requirement of at least 75% of ET. At the same time, moderate N fertilizer of 160 kg ha^{-1} will be adequate for shallot growth and yield. Based on the SPI analysis, the precipitation pattern in Mesuji is dominated by the normal index that adequate water will be available. The Aquacrop model simulated the shallot yield fairly; it gave an estimation of 11.376(W25), 14.175(W50), 16.759(W75), and 19.451 (W100) ton ha^{-1}, while the fresh yield from field observation resulted were 10.810 (W25), 17.032 (W50), 17.351 (W75) and 13.649 (W100) ton ha^{-1}. Accurate crop canopy cover measurement and precise time of shallot water need are factors that need more study in future research. More field observations have to be conducted to secure the model validation.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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