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Determination of the Tolerance of Shallot Varieties at Water Level Depth by Water-saturated Cultivation in Tidal Land

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Abstract Pyrite is a major problem in agricultural cultivation in tidal swamp land, so special technology is needed to obtain optimal agricultural yields, especially shallots. The aims of this study were: 1) To determine shallot varieties that are tolerant to water saturation cultivation with various depths of the water table on growth percentage, shoot age, plant height, number of leaves, dry weight, and productivity, 2) To find and determine the depth of the water table soil suitable for shallots with water-saturated cultivation technology in tidal land for Fe and Al stresses. The materials used were six shallot varieties of Bima Brebes, Bauji, Manjung, Tajuk, SS Sakato, and Batu Ijo, chicken manure, Dolomite, Urea Fertilizer, ZA, TSP, and KCl. A split plot research design was used with a randomized block design (RBD) with three replications. The first factor was the depth of the groundwater table as the main plot, which consisted of 3 treatment levels, namely 10, 20, and 30 cm. The second factor was shallot varieties as subplots consisting of 6: Bima Brebes, Bauji, Manjung, Tajuk, SS Sakato, and Batu Ijo. The results showed that the appropriate water level for shallot cultivation with water-saturated cultivation on tidal land was 20 cm. Adaptive varieties are Bima Brebes, medium Batu Ijo, and sensitive SS, Sakato. The highest productivity was the Bima Brebes variety and SS Sakato variety which was sensitive to Fe and Al poisoning. The Bima Brebes variety is a tidal-tolerant variety with water-saturated cultivation technology on tidal land.

Keywords Shallot, Tidal Swamp, Saturated Soil Culture, Water Depth

1. Introduction

The threat of a food crisis in the world and the Indonesian government are strongly committed to guaranteeing national food adequacy. One of the strategic approaches is to increase food production capacity. In 2021, national shallot production is reported to have increased by 10.4%, reaching around 2 (two) million tons, compared to 2020 production which reached around 1.8 million tons to the 2022 GFSI Report. With an increasing population, raw materials are required. This staple also continues to increase because shallots are 2 (two) of the 9 (nine) national staple foods. The population of the planet is expected to reach billion dollars by 2030, and manoeuvre increased food manufacturing attempts [1].

Indonesia has tidal land with an area of 20.1 million ha [2], around 9.53 million ha is suitable for agricultural cultivation and has the potential as a corn and soybean production area [3]. Utilization of tidal land requires an appropriate technical culture, namely water-saturated cultivation (BJA). BJA technology is a water management system that can affect the physical, chemical, and biological conditions of the soil. A groundwater table that is maintained about 20 cm below the soil surface from the beginning of planting to harvest will result in relatively reductive soil conditions.

Saturated soil culture (SSC) technology cultivates plants by providing continuous irrigation and keeping the water level below the soil surface so that the layer beneath the roots is saturated. SSC technology improves soil fertility by reducing the solubility of Al and Fe, thereby increasing soil pH and availability of P, K, Ca, and Mg [4]. Besides that, SSC technology has increased nitrogenase activity and N, P, and K nutrient absorption in soybeans [5].

One of the challenges that make efforts to develop shallots in tidal lands is the absence of tolerant varieties to be developed in tidal lands experiencing double stress of Fe and Al and the water table depth which is suitable for water-saturated cultivation of shallots in tidal lands is unknown. Shallot varieties that are good at the beginning of plant vegetative growth will adapt well when experiencing Fe and Al stress in tidal land. So that it can determine the varieties of shallots that are tolerant, moderate, and sensitive. The purpose of this experiment is to identify the characteristics that have a significant effect on the selection of Fe and Al stress tolerance at various water depths with water-saturated aquaculture in tidal lands.

2. Materials and Methods

From June to August 2022, this study was carried out in an overflow type B tidal swamp that was only inundated by high tides [6], in Mulyasari Village, Tanjung Lago District, Banyuasin Regency, South Sumatra Province, Indonesia (2°32'54" LS and 104°39'23" E). The experiment employed a three-factor completely randomized method. Three block designs that are identical. Split plots with three replicates were used in the experiment. The main plot was concerned with water table depth and had three treatment levels: 10, 20, and 30 cm below the soil surface. Six shallot varieties were grown in the subplots: Bima Brebes, Bauji, Manjung, Tajuk, SS Sakato, and Batu Ijo. For watering, irrigation furrows surround each main plot in SSC. Water is applied at the start of the planting process.

Experimental plots were made measuring 5 x 2 m. A canal ditch 30 cm wide and 40 cm deep surrounds each plot. The ditches were filled with water up to 20 cm from the canal's bottom (20 cm water level from the ground). And from planting to harvest, it is needed to ensure that the layers beneath the roots are saturated with water. Following that, 10 tons ha^{-1} of chicken manure and 2 tons ha^{-1} of lime were applied. A canal ditch 30 cm wide and 40 cm deep surrounds each plot. The ditches were filled with water up to 20 cm from the canal's bottom (20 cm water level from the ground). From planting to harvest, so that the layers of the roots are saturated.

Fertilization was carried out according to the recommended dosage [7]: pre-plant urea 47 kg ha^{-1}, ZA 100 kg ha^{-1}, SP-36 311 kg ha^{-1}, and KCl 56 kg ha^{-1}. Then fertilization at 2 WAP, namely Urea 93 kg ha^{-1}, ZA 200 kg ha^{-1}, and KCl 112 kg ha^{-1}. Fertilization at 5 MST, namely, Urea 47 kg ha^{-1}, ZA 100 kg ha^{-1}, and KCl 56 kg ha^{-1}. Maintenance consists of canal maintenance involves weeding and pest and disease.

Percentage of growth power (%), is calculated in the number of plants that grow in each experimental plot at 1 WAP (Weeks After Planting). Plant height measurement is done from the ground surface at the top (highest leaf). At 1, 2, 3, 4, 5, and 6 weeks after planting, measurements were made (WAP). A number of leaves: Counting the number of leaves is carried out on leaves that are perfectly formed in each clump. Counts were made at, 2, 3, 4, 5, and 6 MST. The number of leaves per plant is all fully formed leaves in each clump. Productivity is calculated by calculating the average tile weight x 10,000 m^2/tile area. The sensitivity of varieties to water level with water-saturated cultivation is determined by equation [8]:

$$S = \frac{(1 - \frac{Yp}{Y})}{(1 - \frac{Xp}{X})}$$

Remarks:
SI = Sensitivity Index
Yp = The average value of certain variables in varieties that are not under stress
Y = The average value of certain variables on varieties that are under stress
Xp = The average value of certain variables in all varieties that are not under stress
X = The average value of certain variables in all varieties that are under stress
Tolerance criteria based on sensitivity index values are:
Tolerant = $S \leq 0.5$
Moderate = $0.5 < S \leq 1.0$
Sensitive = $S > 1.0$

ANOVA has been used to analyze the data prior to actually proceeding the with DMRT (Duncan Multiple Range Test)) posthoc test at a 95% confidence interval. The software used for the analysis of variance, correlation, principal components, and discriminant analysis was SAS version 9.0, Minitab, and Microsoft Excel 2016. The tolerant and sensitive categories were grouped based on the sensitivity index value of the water table depth, varieties with tolerant category as the first group and sensitive category genotypes as the second group. The characters to be analyzed are standardized using the formula $Z_{ij} = (X_{ij} – X_i)/ S_i$, where Z_{ij} is the value of the standardized character of each shallot variety, X_{ij} is the data for each character of each variety, and S_i is the standard deviation of the character.

3. Result and Discussions

On a single-factor basis, shallot varieties planted at a water level depth of 20 above the soil surface had better growth and production than those at a depth of 10 and 30 cm [9]. [10] The formation of plaque on the root surface is related to the oxidizing ability of Fe^{2+} in the roots. Iron oxidation is affected by the diffusion of oxygen into the rhizosphere through the root aerenchyma. Root Aerenchyma development is influenced by ethylene production in the roots. The larger the size of the aerenchyma formed, the smoother the air diffusion so that the oxidation of Fe^{2+} to Fe^{3+} is faster and the formation of iron plaques increases.

The results of the analysis of variance are in (Table 1). Treatment G and treatment E had a significant effect on all observed parameters but had no significant G x E interaction. The G treatment which had a significant effect illustrated the differences in the response to the observed characters caused by the genotype treatment. Treatment E, which has a significant effect, illustrates that there are differences in the response to the character of the observations caused by different environmental treatments. A real G x E interaction means that there is a change in the response shown by a genotype in a different environment.

Plants with high adaptability (tolerance) can develop and produce harsh environments or when below extreme stress by Fe and Al [11], [12], despite a decrease in output. Characters that can show differences in each environment are very important in the adaptation mechanism of shallot varieties to Fe and Al stress in tidal land.

Plants can directly absorb iron in the form of Fe^{2+} ions. Ferrous iron (Fe^{2+}) can enter through the root membrane by diffusion, then enter into the root cortex cells to the xylem by symplast or apoplast after passing through the cassava band [13], [14]. Ferrous iron that has entered the roots (epidermis, cortex, endodermis, and xylem vessels) can then be transported to the shoots/leaves through the transfer stream to the spaces between cells. In leaf cells, Fe^{2+} acts as a catalyst for the formation of several types of active oxygen, such as superoxide, hydroxide radicals, and H_2O_2 [15].

3.1. Correlation Analysis

Correlation analysis was performed to determine the degree of similarity between the observed characters. [16] and [17] reported on correlation analysis, which also aims to obtain entry requirements in concurrent choice. The Pearson correlation analysis results (Table 2) show a positive correlation between the parameters growth percentage, plant height, and number of leaves. Characters with a strong positive correlation could be used as a starting point for principal component analysis [18], [19]. Characters that are positively correlated can be used in the character selection process. The percentage of growth of shallots is calculated by calculating the population percentage of normal growth of shallots divided by the number of populations planted and multiplied by 100%, which is done at the age of 7 weeks after planting. Soil conditions in tidal lands with high Fe and Al content can be overcome by adjusting the water level through water-saturated cultivation so that Fe^{3+} and Fe^{2+} tend to be reductive. The pH will increase and be able to suppress the content of oxidized pyrite because the upper root layer, which is sufficiently oxygenated, will increase root ethylene by increasing the ACC precursor. Nitrogen in the soil also plays a role in the growth of shallots because the application of urea fertilizer at the beginning of the vegetative growth and the generative phase can stimulate flowering in shallot plants. This aligns with the opinion [20] that fertilizer can stimulate shallot plants' flowering. In addition, the application of N, P, and K fertilizers can also increase the growth and production of shallots. This aligns with research [21] that soils given N, P, and K fertilizers can increase soil fertility so that biomass production and carrying capacity are optimal.

Table 1. Average and analysis of variance

Observational Variables	Means ± SD			G x E	Coefficient of variance (%)
	10 Water Depth	20 Water Depth	30 Water Depth		
Growth percentage	31,66±0,88	30,94±3,95	36,22±2,04	*	3,23
Growth of shoots	28,00±2,33	28,22±2,14	30,00±3,17	*	8,68
Plant height	27,50±2,52	28,78±2,45	29,94±4,02	*	9,38
Leaves Number	29,39±1,27	31,38±3,29	27,10±0,85	*	6,27
Dry weight	26,77±2,69	27,88±0,51	28,83±0,42	*	9,79
Productivity	28,44±2,22	31,44±3,67	31,72±2,86	*	8,66

Note: *markedly different at the 5% level.

Table 2. Correlation analysis of Growth Percentage, Growth of Shoots, Plant Height, Leaves Number, Dry Weight, and Productivity of shallot varieties on tidal swamp saturated soil culture

	GP	GS	PH	LN	DW	PD
GP	1.00	0.408*	0.476*	0.998**	-0.983**	0.083
GS		1.00	0.926**	0.457*	0.193	0.797**
PH			1.00	0.464*	0.195	0.125
LN				1.00	-0.982**	0.997**
DW					1.00	0.641*
PD						1.00

Remarks: **= Correlation at 0.01 (2-tailed) is significant; *=Correlation at 0.05 is significant (2-tailed). GP = Growth Percentage, GS = Growth of Shoots, PH = Plant Height, LN = Leaves Number, DW = Dry Weight, PD = Productivity

3.2. Principal Component Analysis

Principal Component Analysis (PCA) is a data processing technique that can compress data sets from high dimensions into lower dimensions while retaining the information contained in the data [22]. According to [23], this PCA analysis can be used as a regression equation by utilizing the variable coefficients for each character. The coefficient is a variable diversity vector that determines the position of an object. The use of standardized PCA can prevent the effects of multicollinearity in determining character weights in multivariate regression [24]; [25] so that the resulting model is not overestimated. Therefore, determining the regression formula using PCA is more stable than determining the regression directly [26].

The results of the principal component analysis show that the principal component (PC 1) provides an explanation for the diversity of variable percentages of growth by 83% while the principal component (PC2) is 71%, and the principal component (PC3) is 45% (Table 3). The principal component (PC1) has a high contribution, so characters that are important for the selection process can be chosen based on the principal component (PC1). The chosen characters have a high importance in the main component (PC1), these characters are growth percentage, growth of shoots, plant height, leaves number, dry weight, and productivity. The growth percentage and productivity characters can be chosen as selection characters because they have a large value in the 3rd main component. The accumulated level of contribution to the principal component (PC2) and principal component (PC3) is 71% and 45% so the characters selected Important characters can be described in the two components listed above. [27]; [28] reported that the characters of the number of leaves and production gave the highest value to the principal components (PC 1) and (PC 2).

In PC1, it can be seen that growth percentage, growth of shoots, growth of shoots, and productivity provide information on sources of greater diversity than the variable leaves number, PC2) and dry weight (PC3). This shows that the four germination variables in PC1 are morphological characters that contribute to the ability of shallot varieties to adapt to Al and Fe stress in tidal soils and are selection characters in the vegetative growth phase.

Table 3. Principal Component Analysis of the observed parameters

Characters	Loading score of primary Component		
	PC 1	PC 2	PC 3
Growth percentage (%)	0,70	-0,39	0,49
Growth of shoots	0,75	0,37	-0,52
Growth of shoots	0,88	0,39	0,25
Leaves number	-0,26	0,38	0,45
Dry Weight	0,33	-0,64	-0,03
Productivity	0,67	0,17	0,48
Eigenvalue	0,75	1,53	2,72
Proportion (%)	0,12	0,25	0,45
Cumulative (%)	0,83	0,71	0,45

The plant height and leaf number variables had relatively higher variability compared to other variables, meaning that the variegated shallot varieties tested at various depths and Al and Fe stresses showed different responses on tidal land with water-saturated cultivation. This is in line with the opinion that the application of saturated soil culture will cause pyrite to be in a reductive state because part of the soil pore space is filled with water [29]. In addition, by applying 10 tons/ha of organic fertilizer and dolomite at a dose of 2 tons/ha as organic matter for early planting growth in fields that have a pH of 3.81 – 4.35. This is in accordance with the opinion [30] of the provision of ameliorants on tidal lands.

Principal component analysis (PCA) Score Plot and Loading Plot from Figure 1 show that the diversity of the six variables is relatively similar because the vector lengths are the same. The narrower the two variables are made, the higher the positive correlation, such as plant height, leaf number, and productivity have a relatively high positive correlation. Meanwhile, if the angle is obtuse (opposite), the correlation is negative, such as growth percentage, growth of shoots, and dry weight. This means that the growth percentage, growth of nodes, and dry weight also form their own group based on the similarity of the observed variables in shallot plants.

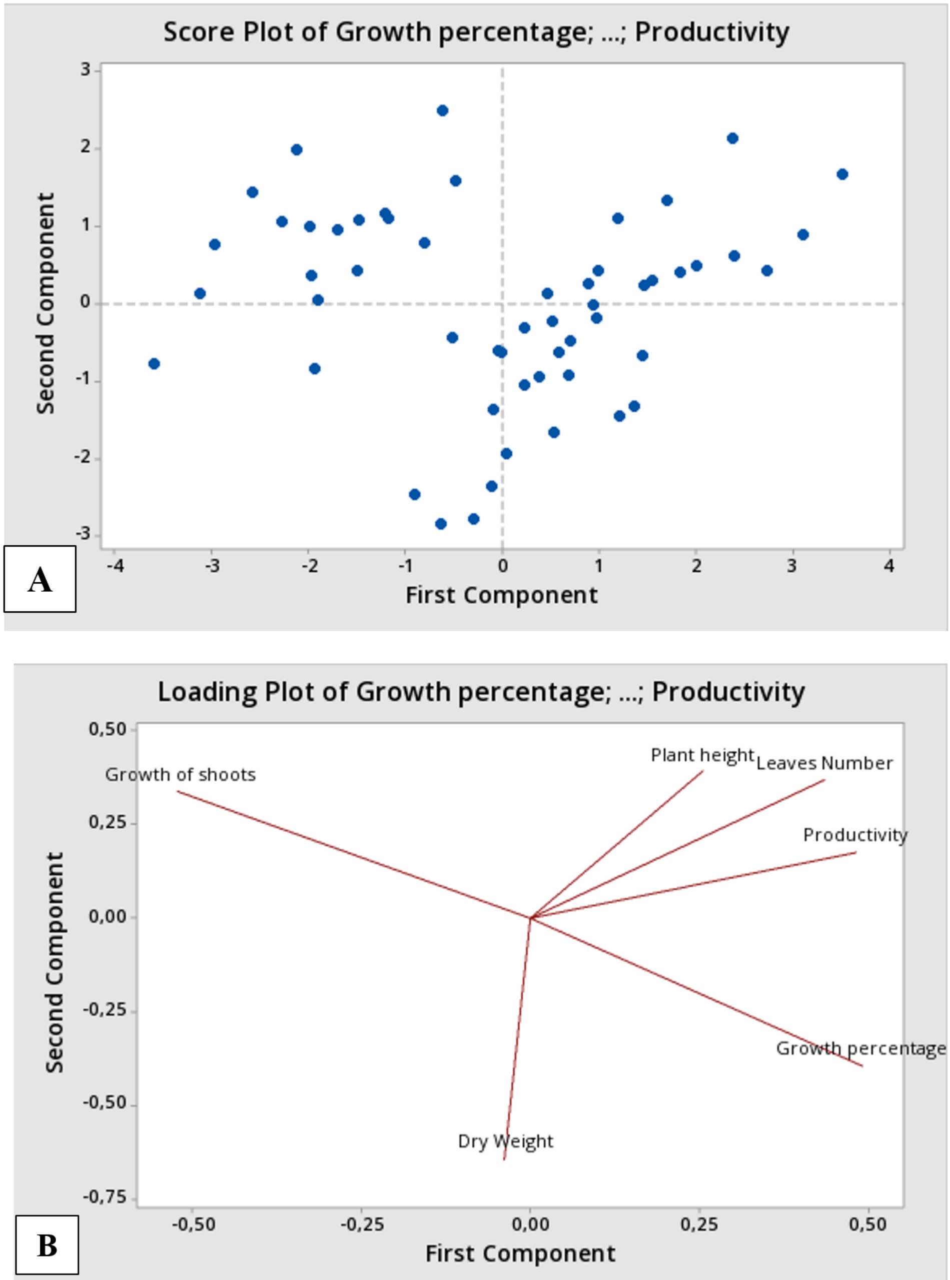

Figure 1. Principal component analysis (PCA) of 6 shallot varieties under Fe, Al toxicity and water depth. A: Score Plot (Second Component) of Growth Percentage, Growth of Shoots, Plant Height, Leaves Number, Dry Weight and Productivity. B: Loading Plot (Second Component) of Growth Percentage, Growth of Shoots, Plant Height, Leaves Number, Dry Weight and Productivity

3.3. Sensitivity Index

Determination of the tolerance results obtained in Table 4 shows that four shallot varieties are in the tolerant category, 1 variety is in the moderate category and 1 variety is in the sensitive category. The grouping of drought sensitivity properties is divided into 3 major groups, namely tolerant, moderate, and sensitive. The division of these three groups of tolerance properties will later be used as a reference for the index to estimate the variety group based on the water table depth sensitivity index based on the characters observed in Fe and Al stress conditions with water-saturated cultivation in tidal land. The shallot varieties of Bima Brebes, Bauji, Manjung, and Tajuk grow shoots faster, and the growth percentage and the plant height and leaves number were higher at water depths of 10, 20, and 30 cm because they have good adaptability to lowland areas like in this study area compared to SS Sakato and Batu Ijo. [31]; [32] reported that the Sakato variety was more suitable in the highlands and could produce a production of shallots of 27.62-29.44 tons/ha. In general, the tidal area is located in the lowlands.

Table 4. Sensitivity index of shallot varieties at various depths of the water table with water-saturated cultivation in tidal fields

Variety	GP	GS	PH	LN	DW	PD	Average Index	Sensitivity
Bima Brebes	0,41	0,32	0,45	0,21	0,39	0,27	0,39	Tolerant
Bauji	0,51	0,47	0,39	0,62	0,57	0,32	0,48	Tolerant
Manjung	0,42	0,55	0,67	0,51	0,42	0,25	0,47	Tolerant
Tajuk	0,42	0,45	0,51	0,38	0,48	0,45	0,44	Tolerant
SS Sakato	1,89	0,81	1,62	0,80	0,87	1,52	1,25	Sensitive
Batu Ijo	0,56	0,77	0,61	0,54	0,76	0,52	0,62	Moderate

Remarks: GP = Growth percentage, GS = Growth of shoots, PH = Plant height, LN = Leaves Number, DW = Dry weight, PD = Productivity

4. Conclusions

The characters used in determining the selection of Fe and Al tolerant cultivar shallots with various water table depths in tidal land in the phases of growth percentage, growth of shoots, plant height, leaves number, dry weight, and productivity. It shows that Bima Brebes, Tajuk, Manjung, and Bauji are in the tolerant category, Batu Ijo is in the moderate category and SS Sakato is in the sensitive category.

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