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Research Article

Nutrient Uptake, Growth and Productivity of Soybean Cultivars at Two Water Depths Under Saturated Soil Culture in Tidal Swamps

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Abstract

Background and Objective: Saturated soil culture is a cultivation technology that provides continuous irrigation and maintains a constant water depth. This results in a saturated subsoil layer. Soybeans can perform poorly in these conditions due to the negative effects of saturated soil at the beginning of the growth. However, soybeans eventually acclimatize and improve soybeans growth. This technology is appropriate to prevent pyrite oxidation in tidal swamps and has been proven to increase soybean yields in tidal swamps. The aim of the research was to study the effect of water depth and cultivar on the nutrient uptake, growth and productivity of soybeans. **Materials and Methods:** The experiment was conducted at Banyuurip, Tanjung Lago, Banyuasin Regency and South Sumatera Province, Indonesia (28 m above sea level, 2°39'32" South latitude and 104°43'618" East longitude). The experiment was arranged in a split plot design with three replications. The main plot was at a water depth consisting of no water (dry culture), 10 and 20 cm under the soil surface, while the subplot cultivars consisted of Ceneng, Cikuray, Lokal Malang and Tanggamus. **Results:** The nutrient uptake and growth of soybeans at water depths of 20 and 10 cm were higher than those of dry culture. The interaction of water depth and cultivar affected seed yield per plot. The highest soybean seed yield was obtained at water depths of 20 and 10 cm with the Lokal Malang cultivar (3.99 t ha^{-1}), which was not significantly different from the Tanggamus cultivar (4.24 t ha^{-1}). **Conclusion:** The water depth influenced the nodule, root, stalk and leaf dry weight, while the cultivar influenced the nodule and root dry weight.

Key words: Soybean, nutrient uptake, growth, yield, pyrite, saturated soil culture, tidal swamps, marginal land

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The national productivity of soybeans in Indonesia is still low, at only 1.4 t ha^{-1} in 2012, which fulfills only 30% of national demand[1]. Soybeans are needed in Indonesia because the soybean is a significant source of nutrition for the Indonesian people. Therefore, a special effort is needed to fulfill the national demand for soybeans, either by increasing crop productivity or expanding production sites. One of many alternatives to develop soybean cultivation in Indonesia is to optimize the use of marginal land. Tidal swamps are one of the potential marginal land ecosystems for future soybean production. Indonesia has ±20 million ha of tidal swamps; 9 million ha are appropriate for agriculture and 2 million ha are suitable for soybeans[2].

The major constraint of soybean production in a tidal swamp is high pyrite content. Soil pH is decreased when pyrite is oxidized. Djayusman *et al*.[3] reported that high pyrite content suppressed the productivity of soybeans on tidal swamps, constraining production to approximately 800 kg ha^{-1}.

Soil water management can be applied to reduce pyrite content where the soil is in a reductive condition and able to support soybean growth. Saturated soil culture (SSC) technology is method of soil water management that has been studied in the highlands and has succeeded in increasing soybean production[4,5]. This technique has the ability to reduce pyrite and thus increase soybean yield in tidal swamps.

SSC is a technology in cultivation that continuously provides and maintains a constant water depth (±5 cm under soil surface/USS), thus keeping the subsoil layer saturated. This watering process begins from the start of plant growth to the maturity stage in SSC. By keeping the water table constant, soybeans can avoid the negative effects of inundation on their growth. Eventually, soybeans in this system will acclimatize and improve their growth[6].

The response of soybeans to saturated condition varies between cultivars. The later-maturing soybeans adapt better than the early-maturing varieties[4]. Sagala *et al*.[7] found that Tanggamus had a higher yield than Slamet, Wilis and Anjasmoro under the saturated conditions in tidal swamps. The response of black soybean cultivars to SSC in tidal swamps has not been studied yet. Therefore, the objective of this research was to study the effect of water depth and cultivar type on the nutrient uptake, growth and productivity of soybeans under SSC in tidal swamps.

MATERIALS AND METHODS

This experiment was conducted on tidal swamp land in Banyuurip village of Tanjung Lago Sub-District, Banyuasin District, South Sumatera Province, Indonesia (28 m above sea level, 2°39'32" South latitude and 104°43'618" East longitude). The experiment was arranged in a split plot design with three replications. The main plot involved water depth in the irrigation furrow and consisted of no watering (dry culture/DC as a control), 10 and 20 cm of water under the soil surface (USS). Subplots contained four soybean cultivars, three black soybean cultivars (Ceneng, Cikuray, Lokal Malang) and one yellow soybean cultivar (Tanggamus). Each main plot on SSC was surrounded by irrigation furrows for watering. Water was provided at planting time and maintained until the maturity stage, so plots remained in wet conditions. Watering of DC depended on rainfall. The trench cross-section and the size are shown in Fig. 1.

Some fertilizers and lime amelioration were applied at 2 weeks before planting. These included 2 t ha^{-1} of dolomite lime, 400 kg ha^{-1} of SP18 as a phosphorus fertilizer and 100 kg ha^{-1} of KCl as a potassium fertilizer. However, nitrogen fertilizer was sprayed with 10 g L^{-1} of urea at 2, 4 and 6 weeks after planting to support acclimatization. Seeds were inoculated with *Rhizobium* sp. and treated with insecticide consisting of active agent (carbosulphan 25.53%) at the planting date. Seeds were planted in a spacing of 40×12.5 cm, at 2 seeds per hole[7,8].

The observed variables were nutrient uptake, plant dry weight, number of branches, filled pods per plant, empty pods per plant, seed productivity (t ha^{-1}) and 100-seed dry weight

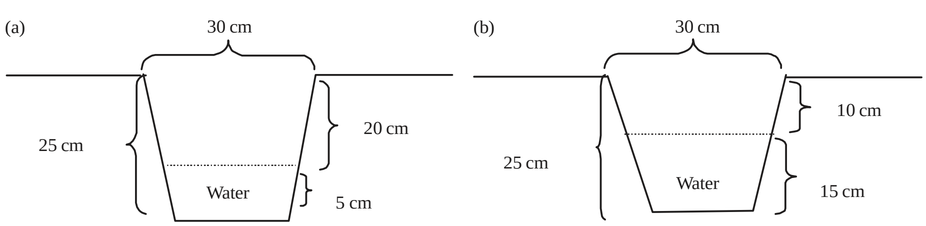

Fig. 1(a-b): Trench cross-section and its size for SSC treatment, (a) 20 cm under soil surface and (b) 10 cm under soil surface at harvest time. All data were analyzed using two-way analysis of variance for split-plot randomized designs using Minitab® 16.1.1. If a significant difference was observed, the data were further analyzed using Duncan's multiple range test at a 5% probability level[9].

RESULTS

Nutrient uptake: Nutrient uptake was indicated by the nutrient content in leaves of the soybean. Table 1 shows that nutrient uptake is affected by cultivation systems on tidal swamps. Nitrogen, phosphorus, potassium and calcium content in soybean leaves cultivated with SSC was higher than those cultivated with DC. They were respectively 509-523% (5 fold); 3,142-3,428% (31-34 fold); 4,281-4, 719% (43-47 fold) and 9,994-10,200% (100-102 fold) of soybean leaf nutrient contents in DC. However, the difference in the water depth of SSC treatments (10 and 20 cm USS) did not result in differences in nutrient absorption.

Table 2 shows the differing abilities of four soybean cultivars in taking up nutrients in their adaptation to tidal swamps. The Lokal Malang cultivar absorbed all the nutrients (nitrogen, phosphorus, potassium and calcium) more effectively than other cultivars. However, there were no significant differences between Lokal Malang and Tanggamus.

The interaction between water depth and cultivar affected the leaves' nutrient uptake of K, but it did not affect the N, P and Ca nutrient uptake. The highest K nutrient uptake was obtained with the Tanggamus cultivar in SSC 10 cm USS and the lowest K uptake was obtained from the Cikuray cultivar in DC (Fig. 2).

Growth: Water depth affected the nodules, roots, stalks, leaves and total biomass dry weight. The nodules, roots, stalks, leaves and total biomass dry weight on saturated soil culture (SSC) at water depths of 10 and 20 cm USS were not significantly different. However, both were significantly higher than in DC conditions. The nodules, roots, stalks, leaves and total biomass dry weight in different water depths can be seen in Table 3.

Cultivar affected the nodule and root dry weights. However, it did not affect the stalks, leaves and total biomass dry weight. The highest nodule number and the heaviest root dry weight were obtained from Tanggamus. The lowest nodule and lightest root dry weight were obtained on Cikuray. The nodule, root, stalk, leaves and biomass total dry weights on different cultivars can be seen in Table 4.

Productivity: The interaction between water depth and cultivar affected the branch number per plant, filled pod number per plant, productivity and 100-seed weight (Table 5-8). Branch number per plant in SSC was higher than that in DC. The highest branch number was obtained from SSC 20 cm in the Lokal Malang Tanggamus cultivars. The lowest branch number was obtained from DC in the Lokal Malang cultivar. The branch number per plant from different water depths and cultivars can be seen in Table 5.

Filled pod number, seed yield and 100-seed weight of each cultivar in SSC 10 and 20 cm USS were higher than those in DC. With water depths of 10 and 20 cm, filled pod numbers and seed yield of the Lokal Malang cultivar were

Table 1: Leaves nutrient uptake in different water depths

		Water depth in saturated soil culture (g/plant)	
Nutrient uptake	Dry culture (g/plant)	20 cm USS	10 cm USS
Nitrogen (N)	0.94[b]	4.79[a]	4.92[a]
Phosphorus (P)	0.01[b]	0.22[a]	0.24[a]
Potassium (K)	0.03[b]	1.37[a]	1.51[a]
Calcium (Ca)	0.01[b]	1.50[a]	1.53[a]

Numbers followed by the same letter at the same row are not significantly different to Duncan's multiple range test at 5%

Table 2: Leaves nutrient uptake for different cultivars

	Varieties (g/plant)			
Nutrient uptake	Ceneng	Cikuray	Lokal Malang	Tanggamus
Nitrogen (N)	2.319[b]	2.468[b]	4.252[a]	4.037[a]
Phosphorus (P)	0.110[c]	0.128[bc]	0.205[a]	0.189[ab]
Potassium (K)	0.523[c]	0.860[bc]	1.295[a]	1.206[ab]
Calcium (Ca)	0.786[b]	0.679[b]	1.467[a]	1.132[ab]

Numbers followed by the same letter at the same row are not significantly different in Duncan's multiple range test at 5%

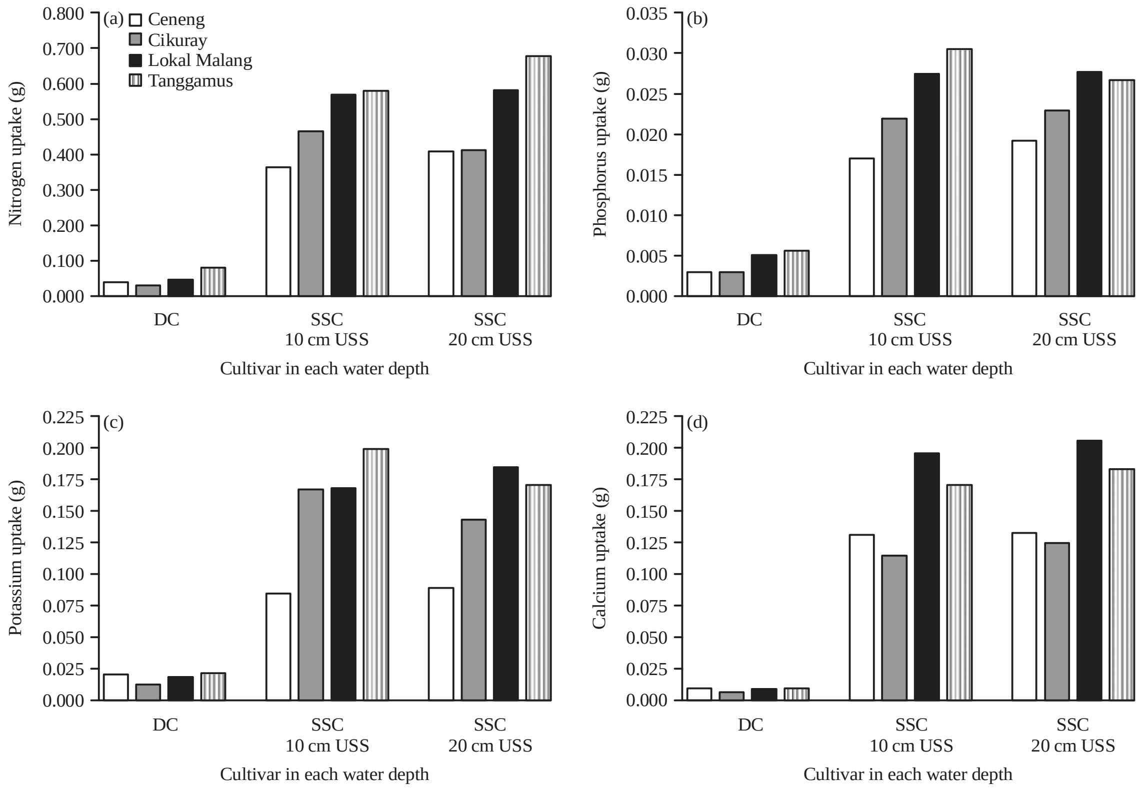

Fig. 2(a-d): Leaves nutrient uptake of four soybean cultivars in saturated soil culture and in dry culture
DC: Dry cultivation, SSC: Saturated soil culture, USS: Under soil surface

Table 3: Nodules, roots, stalks, leaves and biomass total dry weight in different water depths

		Water depth in saturated soil culture (g/plant)	
Variables	Dry culture (g/plant)	20 cm	10 cm
Leaves dry weight	1.71[b]	10.14[a]	9.98[a]
Stalk dry weight	1.60[b]	16.97[a]	15.92[a]
Root dry weight	0.43[b]	1.60[a]	1.69[a]
Nodule dry weight	0.00[b]	0.82[a]	1.09[a]
Total biomass dry weight	3.74[b]	29.53[a]	28.68[a]

Numbers followed by the same letter at the same row are not significantly different in Duncan's multiple range test at 5%

Table 4: Nodule, root, stalk, leaves and biomass total dry weights of different cultivars

	Cultivar (g/plant)			
Variables	Ceneng	Cikuray	Lokal Malang	Tanggamus
Leaves dry weight	6.53[a]	6.41[a]	8.44[a]	7.72[a]
Stalk dry weight	12.14[a]	10.59[a]	11.65[a]	11.59[a]
Root dry weight	1.20[ab]	0.97[b]	1.25[ab]	1.54[a]
Nodule dry weight	0.52[b]	0.48[b]	0.57[b]	0.97[a]
Total biomass dry weight	20.39[a]	18.45[a]	21.91[a]	21.82[a]

Numbers followed by the same letter at the same row are not significantly different in Duncan's multiple range test at 5%

Table 5: Branch number per plant on the different water depth and cultivar

	Cultivar			
Water depth	Ceneng	Cikuray	Lokal Malang	Tanggamus
DC	2.0[de]	2.0[de]	1.5[e]	2.1[d]
SSC-10 cm	3.7[bc]	4.1[abc]	4.0[bc]	3.7[bc]
SSC-20 cm	3.6[c]	4.2[ab]	4.6[a]	4.6[a]

Numbers followed by the same letter are not significantly different in Duncan's multiple range test at 5%. DC: Dry culture, SSC: Saturated soil culture

Table 6: Filled pod number per plant in the different water depths and cultivars

	Cultivar			
Water depth	Ceneng	Cikuray	Lokal Malang	Tanggamus
Dry culture	7.0[d]	8.2[d]	4.4[d]	8.2[d]
SSC-10 cm	65.4[c]	62.7[c]	84.7[b]	92.1[ab]
SSC-20 cm	65.4[c]	53.7[c]	102.8[a]	100.0[ab]

Numbers followed by the same letter are not significantly different in Duncan's multiple range test at 5%

Table 7: Seed yield (t ha^{-1}) on the different water depth and cultivar

	Cultivar			
Water depth	Ceneng	Cikuray	Lokal Malang	Tanggamus
Dry culture	0.26[e]	0.47[e]	0.31[e]	0.54[e]
SSC-10 cm	3.45[bc]	2.75[d]	3.99[ab]	3.93[ab]
SSC-20 cm	3.33[c]	2.36[d]	3.99[ab]	4.24[a]

Numbers followed by the same letter are not significantly different in Duncan's multiple range test at 5%

Table 8: 100-seed weight (g) at different water depths and cultivars

	Cultivar			
Water depth	Ceneng	Cikuray	Lokal Malang	Tanggamus
Dry culture	9.60[de]	10.00[cd]	9.02[e]	10.24[cd]
SSC-10 cm	11.64[b]	13.59[a]	10.11[cd]	11.59[b]
SSC-20 cm	10.76[bc]	14.00[a]	10.21[cd]	11.18[b]

Numbers followed by the same letter are not significantly different in Duncan's multiple range test at 5%

significantly higher than Cikuray and Ceneng. However, this was not significantly different from Tanggamus. The highest filled pod number was obtained from Lokal Malang cultivar in SSC 20 cm USS (102.8). However, the highest seed yield was obtained on Lokal Malang cultivar with SSC 10 and SSC 20 cm USS (3.99 t ha^{-1}). This indicates that the Lokal Malang cultivar is a black soybean cultivar well adapted to tidal swamps under SSC. The highest 100-seed weight was obtained with SSC 10 and 20 cm USS in the Cikuray cultivar (Table 1-3).

DISCUSSION

SSC guaranteed the availability of water in soil layers. The water in the irrigation furrow was percolated through the soil to reach the center of the bed. The experiment[10] showed that water could be percolated through a 2×4 m-wide bed. The width of the bed in this study was 2 m, so the water was able to reach the center of the bed, creating a reductive state. The nutrients dissolved in the water could then be taken up by the plants, absorbed by the roots and sent to the leaves. Nutrient uptake ability between SSC and DC in this study was also related to the environment of the root zone. According to Priatmadi and Haris[11] and Mathew *et al.*[12], the reductive state of the tidal swamp soil avoided pyrite oxidation and increased soil pH. Pyrite produces H^+, Fe^{3+} and H_2SO_4. H^+ reduces pH and Fe^{3+} and H_2SO_4 can poison the roots. As a result, root growth and activity would be disrupted by this damaging environment. Avoiding pyrite oxidation would assure the availability of nutrients in the soil: Al would be increased in low pH and would bind some nutrients, especially P, in the soil matrix. Bound nutrients would not be available to the plants[13].

It was also observed that the four soybean cultivars showed a different response to the watering system on the tidal swamp. This difference was expressed by genes in each cultivar in response to the environment, as plant growth is a gene-environment interaction (GXE) expression[14].

Nutrient uptake influenced plant growth and plant growth influenced yield. The result showed the cultivars good at nutrient absorption expressed good growth and the highest yield. Avoidance of pyrite oxidation, availability of water and nutrients and high levels of solar radiation intensity (approx. 1000 W m^{-2}) supported good plant growth and yield under SSC on tidal swamps but did not occur in DC conditions. According to Sagala[15], the high productivity of soybeans under SSC on tidal swamps was caused by the high levels of solar radiation and sufficiency of water and soil nutrients by the application of lime and fertilizer in this location.

It was found in this study that cultivation systems would influence the growth and yield of black soybeans in tidal swampss. SSC is appropriate to increase black soybean yield on tidal swamps and there was no statistical difference between 10 and 20 cm USS in some parameters observed. The result of this study reinforces the result of the previous study in SSC experiments for yellow soybeans in tidal swamps[7,13,16]. This study demonstrated the importance of applying saturated soil culture to cultivate soybeans in tidal swamps. All soybean cultivars had a good growth and high yield when cultivated under saturated soil culture in tidal swamps. However, these findings will be more compelling when rainfall data is included in order to know the water levels needed to avoid pyrite oxidation.

CONCLUSION

The water depths and cultivars, as single factors, influenced the N, P, K and Ca nutrient uptake in soybeans. The water depth influenced the nodule, root, stalk and leaf dry weight, while the cultivar influenced the nodule and root dry weight. The nutrient uptake and growth of soybeans at water depths of 20 and 10 cm were higher than those in dry culture. The interaction between water depth and cultivar affected the K nutrient uptake, branch numbers per plant, filled pod number per plant, productivity and 100-seed weight. The highest filled pod number was obtained in the Lokal Malang cultivar at SSC 20 cm (102.8). The highest soybean seed yield was obtained at a water depth of 20 cm and 10 cm with the Lokal Malang cultivar (3.99 t ha^{-1}) and was not significantly different from the Tanggamus cultivar (4.24 t ha^{-1}).

SIGNIFICANCE STATEMENT

Soybean is one of the most important culinary ingredients in Indonesia. A variety of traditional cuisines in Indonesia use soybean as a key condiment. In addition to taste, soybean is important because it is a source of nutrition, especially protein, in Indonesian cooking. Therefore, increasing productivity of black soybeans needs to be a national concern. This study investigates nutrient uptake, growth and yield of black soybeans under saturated culture that can be beneficial in increasing soybean yield in tidal swamps. This study will help researchers further to understand the best practices for overcoming pyrite oxidation in tidal swamps based on agronomic techniques that many researchers have not yet been able to explore. Further research may be needed on more efficient ways to apply SCC in tidal swamps.

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