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Response of Corn Varieties under Saturated Soil Culture and Temporary Flooding in Tidal Swamp

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Abstract

Corn is one of the important food crops and feeds in the world. Conversion of agricultural land into non-agricultural land is one of the major causes of the decline in corn production. Saturated soil culture (SSC) is a cultivation technology that gives continuous irrigation and maintains water depth constantly and makes soil layer in saturated condition. This technology can prevent pyrite oxidation in the tidal swamp. This research aimed to study the effect of temporary flooding under saturated soil culture on the growth and productivity of corn. The research was conducted at Karya Bhakti village, Rantau Rasau, Tanjung Jabung Timur, Jambi Province, Indonesia. The experiment used a split plot design with three replications. The main plot is flooding condition, consisted of 1) saturated soil condition continuously, from planting until harvesting time (as control), and 2) saturated soil condition from 0 to 10 DAP (Days after Planting) + flooding from 11 to 13 DAP + saturated soil condition from 14 to 28 DAP + flooding from 29-31 DAP + saturated soil condition from 32 DAP until harvesting time. The subplot is corn variety, “Sukmaraga”, “Bisma”, “Pioneer 27”, and “Bima 20”. “Pioneer 27” had the highest productivity of 9.33 t.ha^{-1}. Corn varieties with moderate tolerance to temporary flooding were “Sukmaraga” and “Bisma”, whereas “Pioneer 27” and “Bima 20” are sensitive to flooding.

Keywords: corn, pyrite, sensitivity index, temporary flooding, tidal swamps.

Introduction

Corn is one of the important food crops besides rice and soybeans, as well as feeds. Corn productivity in Indonesia in 2016 was 5.30 t.ha^{-1} dry shells, whereas the corn consumption was 20 million tons (Suwandi, 2017). Java island is the largest national corn producing area (Komalasari, 2018). Corn productivity in Indonesian islands outside Java is still low, i.e. 4.67 t.ha^{-1}, compared to production in Java, i.e. 5.67 t.ha^{-1}. The harvested area of corn in 2009 was 4.16 million ha, but in 2015 it had decreased to 3.79 million ha (BPS, 2017). Java harvested area of corn in 2015 (2.99 million ha) is four times as large as Sumatera (0.75 million ha).

The decrease of the corn harvested area was due to the conversion of agricultural land to non-agriculture (Kementan, 2015). As a result, the import of dry shelled corn increased by 0.5 million tons in 2016 compared in 2015 (Kemenperin, 2016). One of the ways to increase corn productivity is by growing corns in sub-optimal agricultural land. The utilization of sub-optimal land has important important roles to support sustainable agriculture.

The tidal swamps are sub-optimal lands that are widely found in Indonesia; it is estimated to be around 9.53 million ha (Arsyad, Saidi and Enrizal, 2013). Ismail et al. (1993) stated that tidal swamp lands have agricultural potential, including the tidal swamps located in Jambi Province. The tidal swamp area in Jambi is estimated to be 684,000 ha, and about 30 % (246,481 ha) can be developed into agricultural land (BPTP, 2017). Four types of tidal swamps have been identified. Type A tidal swamp is flooded by large and small tide, type B by small tide, type C and D is not flooded but has a water depth < 50 cm and >50 cm, respectively (Ar-Riza and Alkasuma, 2008). The types of tidal swamp that could be used for corn production is type B, C, and D (Ghulamahdi et al., 2009; Adam et al., 2013).

The problems in using tidal swamp for agricultural land are the occurrence of temporary flooding, high salinity, and oxidation of pyrite or iron oxide, which is very toxic to plants (Noya et al., 2014; Sulistiyani and Putra, 2014). Temporary flooding occurs when the rise of water caused by gravitational forces of the moon meets with the high rainfall, resulting in an overflow of river water and caused flooding in the tidal swamp land of up to 3 hours. On the other hand, pyrite oxidation occurs when tidal swamp land is dry and pyrite will be oxidized to toxic form $Fe(OH)_3$ (Ghulamahdi et al., 2006; Lubis et al., 2016).

Saturated soil culture (SSC) is a cultivation technology that gives continuous irrigation and maintains water depth constantly and makes soil layer in saturated condition. SSC can reduce pyrite oxidation thus support corn growth on tidal swamp (Ghulamahdi, 2017). Selection of corn varieties to grow on tidal swamps affects its productivity. Corn productivity on tidal swamp was still low, i.e. 2.21 $t.ha^{-1}$ (Jumakir and Erizal, 2009). However, the research of temporary flooding in tidal swamps and its effects on corn production is still limited. This study aims to evaluate temporary flooding and SSC on the physiology, growth, and yield of corn, and determine tolerant and high yielding corn varieties to grow in the type B tidal swamp.

Material and Methods

Experimental Site

The experiment was carried out on tidal swamp type B in Karyabakti Village, Rantau Rasau District, East Tanjung Jabung Regency, Jambi Province, Indonesia, from April to September 2018.

Treatments

The experiment was carried out using a split plot design with types of flooding as main plots, and corn varieties as sub-plots. Types of flooding consisted of saturated soil culture (SSC, control), and SSC at 0 to 10 days after planting (DAP) + flooding at 11 to 13 DAP + SSC at 14 to 28 DAP + flooding at 29 to 31 DAP + SSC at 32 DAP until harvest. Four corn varieties, “Sukmaraga”, “Bisma”, “Pioneer 27”, “Bima 20”, were tested, so there were 24 experimental units in total. Each experimental unit consists of 2 m x 9 m plots that were surrounded with 30 cm width x 50 cm depth trenches. Irrigation water was applied continuously from planting until harvest with a water depth of 30 cm below the soil surface (Figure 1). Temporary flooding (TF) was created by supplying irrigation to a water level of 5 cm above the soil surface for three hours (Figure 2).

Dolomite (2 $t.ha^{-1}$) and SP-36 (300 $kg.ha^{-1}$) were applied two weeks before planting. Urea (150 $kg.ha^{-1}$) was applied twice, at planting and at 30 DAP, whereas KCl (100 $kg.ha^{-1}$) was applied at planting. Corn crops were sprayed with 15 $g.L^{-1}$ of Urea with a volume

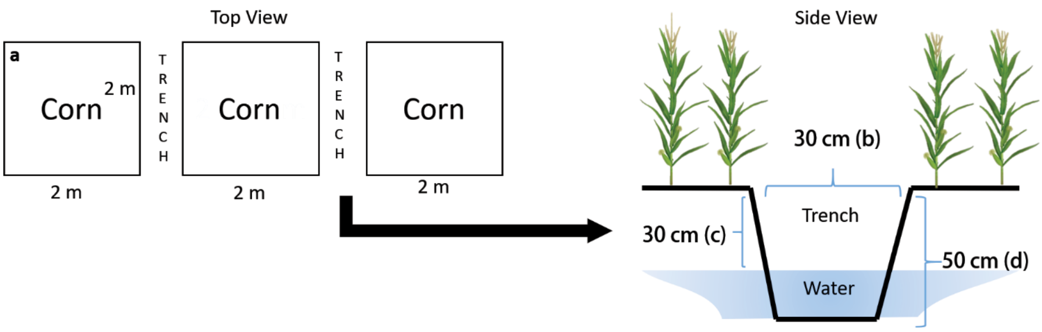

Figure 1. The size of plots (a), trench width (b), water depth (c), trench depth (d) in the saturated soil culture (SSC) treatment.

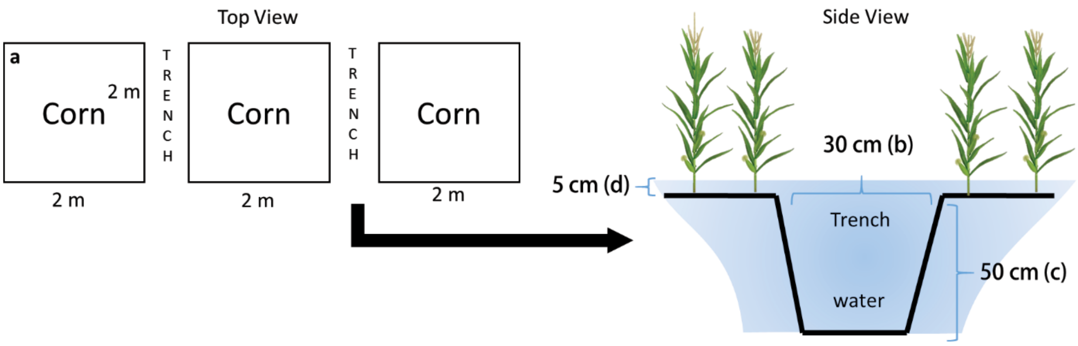

Figure 2. The size of plots (a), trench width (b), trench depth (c), and the height of flooding (d) in the temporary fooding (TF) treatment

water spray of 400 L.ha^{-1} weekly at two to five weeks after planting (WAP). Corn seeds were treated with insecticide fipronil (50 g.L^{-1}) prior to planting, with the spacing of 100 cm x 20 cm (20 plants per plot). Crops were harvested once they reached their physiological maturity, indicated by the presence of 'black layer' on the corn kernels.

Measurement of corn growth consisted of plant height, the number of leaves, stem diameter, leaf area, leaf area index (LAI) on five sample plants per plot. Root volume and root length were measured at four and eight 8 DAP on one sample plant per plot. Physiological measurement consisted of relative growth rate (RGR) and net assimilation rate (NAR), measured on one sample plant per plot, at 4 to 6 and 6 to 8 WAP using formulas from Gardner et al. (1991) as follows:

$$RGR = (\ln W_2 - \ln W_1)/(t_2 - t_1)$$

$$NAR = (W_2 - W_1/A_2 - A_1)/(\ln A_2 - \ln A_1/t_2 - t_1)$$

where

ln is natural logarithm, W_1 is dry weight at t_1, W_2 is dry weight at t_2, t_1 is time one, t_2 is time two, A_1 is Leaf area at t_1, and A_2 is leaf area at t_2.

Stomatal density (SD) were measured on the 5th leaf at 3 WAP and the 7th leaf at 5 WAP on two plant samples per plot. A clear nail polish was used and spread on abaxial leaves, left to dry, and a strip of clear sticky tape was placed over the nail polish. The sticky tape was then peeled off and the leaf section was placed on a microscope slide. Observation was made using 400 x magnification. SD was determined by equation from Xu and Zhou (2008) as follows:

$$SD = \text{number of stomata}/(\pi r^2)$$

Where π = constant (3.14) and r^2 (radius of field of view on 400x magnification).

Leaf greenness were determined on 5 sample plants per plot using Greenness Leaf Colour Chart (Balitsereal, 2007). Measurement was made at three points of each leaf, i.e. edge, midle, and base of the 5th leaf at 4 WAP, and of the 7th leaf at 6 WAP, then the values were averaged (Balitsereal, 2007).

Corn yields were measured on five sample plants per plot. Yield components consist of cob weight, cob length, cob diameter (measured in the middle of each cob), and number of rows per cob, number of kernels per row, the weight of dry seed per cob, 100-seeds dry weight, and productivity.

The sensitivity index (SI) determined by equation described in Fischer and Maurer (1978):

$$SI = (1 - Yp/Y)/(1 - Xp/X)$$

where SI is sensitivity index, Y_p is mean of productivity from all varieties, Y is mean of productivity on SSC, X_p is average productivity from all varieties in TF, X is average productivity from all varieties in SSC. The criteria of tolerance is SI < 0.5 is tolerant, 0.5 < SI < 1.00 is moderate-tolerant, and SI > 1.00 is sensitive. Data was analyzed using SAS 9.4 software (SAS Institute Corp); significant differences between means were further tested using Tukey test with significance level of 5%.

Result and Discussion

Corn growth

There were interactions between types of flooding and corn variety in affecting corn growth at 4 WAP (Table 1).

Types of flooding and corn variety interacted in

Table 1. The effects of types of flooding and corn variety on growth at 4 weeks after planting

Types of flooding	Corn Variety	Plant height (cm)	Root length (cm)	Leaf area (cm^2)	Leaf area index
SSC	"Sukmaraga"	81.60ab	17.00bc	1416.33ab	0.71ab
	"Bisma"	72.67c	17.00bc	1206.57bc	0.6bc
	"Pioneer 27"	84.66a	22.00a	1467.22a	0.73a
	"Bima 20"	76.66bc	19.67ab	1451.77a	0.72a
TF	"Sukmaraga"	65.40d	13.33c	1161.46c	0.57c
	"Bisma"	62.27d	13.33c	1277.52abc	0.66abc
	"Pioneer 27"	63.33d	14.33c	1306.92abc	0.66abc
	"Bima 20"	62.00d	16.33bc	1310.41abc	0.66abc

Note: values followed by the same letters within the same column are not significantly different based on Tukey test α=5%; SSC = saturated soil culture; TF = temporary flooding affecting plant height, root length, leaf area, and leaf area index (Table 1). Corns of all varieties that had temporary flooding were shorter; the decrease in plant height was up to 26% and had shorter roots (Table 1). "Pioneer 27" was the tallest compared to the other varieties (Table 1). The high levels of Al (Aluminum) and Fe (Iron) in tidal swamps inhibited corn growth (Panda et al., 2009; Sutoro, 2012). In addition, flooding can cause increasing availability of Al and Fe in the soil surface, so their levels had started to be toxic to the crops. Research conducted by Roberto (2000) stated that aluminum stress tends to reduce the growth of sensitive corn varieties.

Temporary flooding did not affect the number of leaf per plant and root volume at 4 DAP (Table 2). Stem diameter of the crops in temporary flooding treatment decreased by 17% compared to SSC. Different corn varieties had different stem diameter in response to the types of flooding. "Sukmaraga" had the largest stem diameter, but was not significantly different from by "Pioneer 27" at 4 WAP. According to Ghulamahdi et al. (2016) temporary flooding resulted in the decrease of corn stem diameter.

Flooding significantly reduced stem diameter, root length, and root volume at 8 DAP (Table 3). Corn with SSC has the largest stem diameter, longest roots, and the largest root volume compared to those with temporary floding. Different corn varieties have different vegetative characters, except for leaf area and LAI. "Pioneer 27" has the fastest vegetative growth whereas "Bisma" had the slowest. LAI values were > 2.5 in all treatments. Corn plants that have LAI between 2.5 to 5 have maximum dry matter and high productivity potentials (Goldsworthy et al., 1974).

At 8 DAP corns possibly had adapted to tidal swamp environment (Table 3). Accumulation Al and Fe might have occurred more frequently in the temporary flooding an inhibited growth of roots and stems. Roots became shorter so they absorb less nutrients from the soil, especially phosphorus, which has essential functions in cell division in plants (Ghulamahdi et al.,

Table 2. Effect of flooding and variety on corn growth at 4 weeks after planting

Treatment	Number of leaves per plant[a]	Stem diameter (cm)	Root Volume (ml)
Types of flooding			
SSC	5.25	13.88a	15.92
TF	5.18	11.65b	13.42
Corn variety			
"Sukmaraga"	5.23	13.57a	15.00b
"Bisma"	5.23	12.23b	11.67c
"Pioneer 27"	5.20	13.02a	17.00a
"Bima 20"	5.20	12.24b	15.00b

Note: the values followed by the same letters in the same column are not significantly different based on Tukey test α=5%; SSC = saturated soil culture; TF = temporary flooding

Table 3 Effect of types of flooding and variety on corn growth growth at 8 weeks after planting

Treatments	Plant height (cm)	Number of leaves per plant	Stem diameter (mm)	Root length (cm)	Root volume (ml)	Leaf area (cm^2)	Leaf area index
Types of flooding							
SSC	215.60	11.73	23.75a	26.58a	53.17a	5582.80	2.79
TF	203.67	10.83	22.32b	21.42b	47.42b	5311.40	2.66
Corn variety							
"Sukmaraga"	216.87a	11.50a	22.85ab	24.17b	47.67b	5284.40	2.65
"Bisma"	203.50b	10.90b	21.61b	20.33c	36.33c	5350.50	2.67
"Pioneer 27"	218.00a	11.60a	24.10a	27.83a	58.33a	5460.50	2.73
"Bima 20"	200.17b	11.13ab	23.59a	23.67b	58.83a	5692.90	2.85

Note: values followed by the same letters in the same column are not significantly different based on Tukey test α=5%; SSC = saturated soil culture; TF = temporary flooding

2006; Sairam et al., 2008; Gupta et al., 2013).

Effects of Flooding Treatment on Corn Physiology

Types of flooding or corn variety alone significantly affected stomatal density at 3 WAP, Leaf greenness at 4 WAP, RGR at 6 to 8 WAP, and NAR at 6 to 8 WAP (Table 4). Types flooding and corn variety interacted in affecting stomatal densities at 5 WAP, leaf greenness at 6 WAP, and RGR 4 to 6 WAP (Table 5).

The temporary flooding treatments increased RGR and NAR at 6 to 8 WAP, and decreased leaf greeness at 4 WAP. Different corn varieties demonstrated differences in leaf greeness at 4 WAP, RGR at 6 to 8 WAP, and NAR at 6 to 8 WAP. “Bima 20” has the highest RGR and NAR at 6 to 8 WAP compared to “Pioneer 27”, but it was not significantly diferrent from RGR and NAR of “Sukmaraga” and “Bisma”.

The reduced values of green color intensity due to flooding is an indicator that the crops were nitrogen-deficient (Wang et al., 2012). Balitsereal (2007) reported that corn with leaf greeness value of <4.25 are nitrogen deficient. The RGR and NAR values were higher in temporary flooding than in to SSC. We assumed that the growth and assimilation rate of the plants that had been returned to the optimal condition (SSC) will increase, resulting in speedy recovery.

“Pioneer 27” with temporary flooding had the lowest stomatal density and leaf green intensity values (Table 5). “Bisma” had the highest RGR value at 4-6 WAP in the SSC, whereas with temporary flooding “Bisma” had the lowest Leaf Greenness. Leaf Greenness of the hybrid varieties in temporary flooding at 6 WAP was > 4.5, whereas in the composite varieties it was < 4.5. It was likely that the nitrogen absorption is more effective in hybrid varieties compared to that of the

Table 4. Responses of different corn varieties to saturated soil culture and temporary flooding

Treatment	Stomatal density (mm^{-2}) at 3 WAP	Leaf greenness at 4 WAP	RGR 6-8 WAP (g at per day)	NAR 4-6 WAP ($g.cm^{2\ at}$ per day)	NAR 6-8 WAP ($g.cm^2$ at per day)
Types of Flooding					
SSC	73.46	4.42a	0.027761b	0.00135517	0.00043638b
TF	70.07	3.89b	0.042142a	0.00133249	0.00068543a
Corn Varieties					
“Sukmaraga”	69.64	4.15ab	0.034721ab	0.00134905	0.00052081ab
“Bisma”	67.09	4.04b	0.035374ab	0.00130871	0.00058929ab
“Pioneer 27”	74.74	4.28a	0.027729b	0.00142661	0.00046501b
“Bima 20”	75.59	4.15ab	0.041980a	0.00129094	0.00066851a

Note: values followed by the same letters in the same column are not significantly different based based on Tukey test α=5%. SSC= saturated soil culture, TF = temporary flooding, RGR = Relative growth rate, NAR = net assimilation rate, WAP = weeks after planting.

Table 5. Stomatal density, leaf green color intensity and relative growth rate of different corn varieties under different types of flooding

Flooding condition	Corn variety	Stomatal density at 5 WAP (mm^{-2})	Leaf greenness (at 6 WAP)	RGR 4-6 WAP WAP (g at per day)
SSC	“Sukmaraga”	78.13ab	4.80ab	0.138840bc
	“Bisma”	86.63ab	4.71bc	0.150649abc
	“Pioneer 27”	81.53ab	4.84a	0.141668abc
	“Bima 20”	76.43ab	4.82ab	0.14811abc
TF	“Sukmaraga”	91.72a	4.36d	0.158510ab
	“Bisma”	79.83ab	4.31d	0.1616408a
	“Pioneer 27”	66.24b	4.60c	0.1349306c
	“Bima 20”	83.22ab	4.60c	0.156796ab

Note: the values followed by the same letters in the same column were not significantly different based based on Tukey test α=5%; SSC = saturated soil culture, TF = temporary flooding, RGR = relative growth rate, WAP = week after planting composite varieties. RGR value of composite varieties ("Sukmaraga" and "Bisma") in TF was higher than that of the hybrid variety ("Pioneer 27"). It is possible that early mature varieties had higher RGR than the late mature variety ("Pioneer 27"), even though both of them were under stressed environment.

Yield

The corn yield components were significantly affected by the flooding treatment (Table 6) and its interaction with corn variety (Figure 3). Flooding affected the number of seeds per row, cob weight, and 100-seed dry weight. Corn with SSC treatment had the highest yield components.

"Pioneer 27" had the best cob characters compared to the other varieties, except cob length and 100-seeds dry weight. The cob length of "Sukmaraga", "Pioneer 27", and "Bima 20" lengths similar. Number of rows per cob, 100-seeds dry weight and number of kernels per cob row in "Sukmaraga", "Bisma", and "Bima 20" were similar.

The interaction between types of flooding and corn variety significantly affected yields. "Pioneer 27" with SSC treatment had the highest cob weight (289.09 g), 100-seed dry weight per plant (228.04 g), and productivity of 9.33 t.ha^{-1} respectively. Except for Pioneer, the productivity of the corn varieties with SSC treatment was ± 6 t.ha^{-1}, whereas in "Bisma" it was only 5.87 t.ha^{-1}. On the other hand, "Pioneer 27" in the temporary flooding had the highest productivity compared to the other variety in this treatment. The average corn productivity in the tidal swamp is about 2 to 3 t.ha^{-1} (Jumakir and Endrizal, 2009; Nazemi et al., 2012)

Combination of genetic and environmental factors determines crop productivity. Ghulamahdi (2017) reported that even though the crops are in a stressfull condition, SSC can suppress pyrite oxidation, so the soil pH in the root zone do not become acidic. Therefore, toxic elements including Fe and Al were not available, whereas the essential macronutrients become available. Sagala (2015) stated that the intensity of solar radiation on tidal swamp could reach 1,063 w.m^{-2} in August. High light intensity promotes photosynthesis to the maximum rate. Therefore, supported by the availability of water on the tidal swamp and the availability of nutrients from fertilization, the corn productivity on tidal swamps can be potentially high.

Sensitivity Index

The sensitivity index (SI) of a variety to temporary flooding is determined by its productivity after the flooding treatment. The composite varieties, "Sukmaraga" and "Bisma", have an SI value of 0.71 to 0.77, so they were grouped as moderately tolerant varieties. The hybrid varieties "Pioneer 27" and "Bima 20" have an SI value of 1.05 to 1.32, so they were grouped as sensitive varieties (Table 7).

The intensity and duration of flooding greatly affected the corn yields. Ren (2014) stated that the corn is very sensitive to flood in the V3 stage, which is indicated by the rapid growth of rooting system below the ground rather than the canopy growth. According to Suwarti et al. (2013) corn hybrid varieties are generally sensitive to flood during early vegetative growth; flooding at this stage would reduce corn productivity. In addition, Marschner (2012) reported that composite varieties are more likely to be tolerant than high yielding varieties. "Pioneer 27" had the highest productivity compared to other varieties, even though the crops were flooded.

Table 6. Corn yields as affected by flooding treatments and corn varieties

Treatment	Cob length per plant (cm)	Cob diameter per plant (mm)	Number of rows per cob	Number of kernel per cob row	100-seed dry weight (g)
Types flooding					
SSC	18.03	47.30	14.20	36.75a	29.93a
TF	16.23	46.25	14.07	32.07b	28.20b
Variety					
"Sukmaraga"	17.45a	44.71c	13.60b	34.27b	29.16ab
"Bisma"	16.40b	45.58bc	13.87b	33.00b	27.16b
"Pioneer 27"	17.53a	49.90a	15.67a	37.50a	29.42a
"Bima 20"	17.13ab	46.91b	13.40b	32.87b	30.50a

Note: values followed by the same letters in the same column were not significantly different according to Tukey test α=5%; SSC = saturated soil culture; TF = temporary flooding

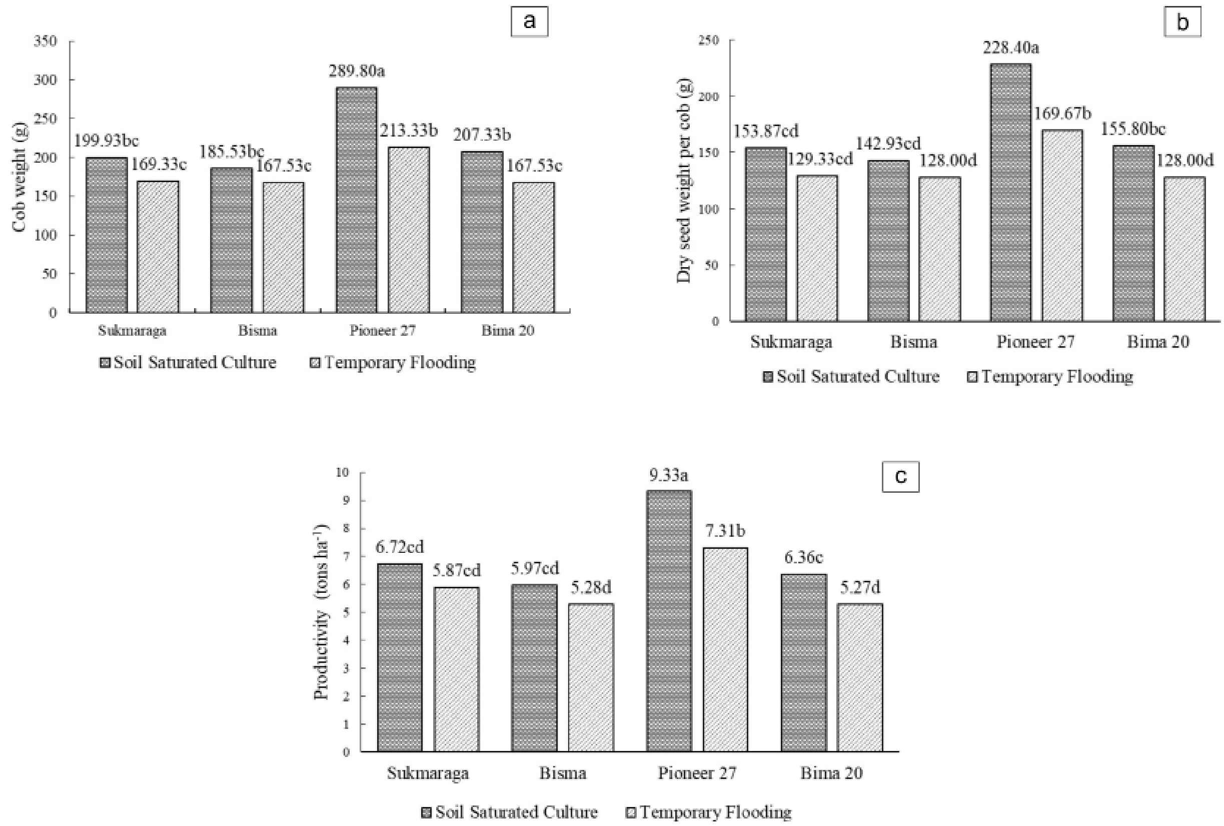

Figure 3. Cob weight (a), dry seed weight per ear (b), and corn productivity (c) of different corn varieties with different types of flooding

Table 7 Corn variety sensitivity index to the temporary flooding

Variety	SSC producitivity ($t.ha^{-1}$)	TF Productivity ($t.ha^{-1}$)	Average productivity ($t.ha^{-1}$)	SI	Sensitivity level
"Sukmaraga"	6.72	5.87	6.30	0.77	Moderate-tolerant
"Bisma"	5.97	5.28	5.63	0.71	Moderate-tolerant
"Pioneer 27"	9.33	7.31	8.32	1.32	Sensitive
"Bima 20"	6.36	5.27	5.82	1.05	Sensitive

Note: SSC = saturated soil culture, TF= temporary flooding, SI = sensitivity index

Conclusion

Different corn varieties demonstrated different growth, physiology, and yields under different types of flooding. All growth variables were the highest in the SSC treatment, except for RGR and NAR at 6 to 8 WAP. "Pioneer 27" had the highest productivity of 9.33 $t.ha^{-1}$. "Sukmaraga" and "Bisma" were the most tolerant varieties to temporary flooding treatment, whereas the "Pioneer 27" and "Bima 20" are the sensitive varieties. "Pioneer 27" in temporary flooding treatment had the highest productivity of 7.31 $t.ha^{-1}$.

References

Adam, H., Susanto, R.H., Lakitan, B., Saptawan, A. and Yazid, M. (2013). The problems and constraints in managing tidal swamp land for sustainable food crop farming (a case study of trasmigration area of Tanjung Jabung Timur Regency, Jambi Province, Indonesia). *International Conference on Sustainable and Agriculture* (S. Baby, and Y. Dan, eds.) pp. 67–72. IACSIT. Singapore.

Ar-Riza and Alkasuma. (2008). Pertanian lahan rawa pasang surut dan strategi pengembangannya dalam era otonomi daerah. *Jurnal Sumberdaya Lahan* **2**, 95–104.

Arsyad, D.M., Saidi, B.B., and Enrizal. (2013). Pengembangan Inovasi Pertanian Di Lahan Rawa Pasang Surut Mendukung Kedaulatan Pangan. *Pengembangan Inovasi Pertanian* **6**, 169–176.

Balitsereal. (2007). “Penggunaan Bagan Warna Daun (BWD) pada Tanaman Jagung”. http://balitsereal.go.id/bwd.pdf [October 16, 2018]

BPS. (2017). “Luas Panen Jagung Menurut Provinsi”. https://www.bps.go.id/ linkTableDinamis/ view/ id/867 [March 1, 2017]

BPTP. (2017). “Peluang Peningkatan Indeks Pertanaman Lahan Rawa Pasang Surut Di Kabupaten Tanjung Jabung Timur”. http://jambi.litbang.pertanian.go.id/ind/images/PDF/Suharyon4.pdf [July 25, 2017].

Fischer, R. and Maurer, R. (1978). Drought resistance in spring wheat cultivars . I Grain yield responses. *Australian Journal Agriculture Research* **29**, 897–912.

Gardner, F.P., Pearce, R.B., and Mitchell, R.L. (1991). “Fisiologi Tanaman Budidaya” (S. Herawati, trans.). UI Press.

Ghulamahdi, M. (2017). “Adaptasi Kedelai Budidaya Jenuh Air Untuk Produktivitas Tinggi di Lahan Pasang Surut”. IPB Press.

Ghulamahdi, M., Aziz, S.A., and Melati, M. (2006). Aktivitas nitrogenase, serapan hara dan pertumbuhan dua varietas kedelai pada kondisi jenuh air dan kering. *Buletin Agronomi*, **38**, 32–38.

Ghulamahdi, M., Melati, M., and Sagala, D. (2009). Production of soybean varieties under saturated soil culture on tidal swamps. *Jurnal Agronomi Indonesia* **37**, 226–232.

Ghulamahdi, M., Ria, S., Lubis, I., and Taylor, P. (2016). Response of five soybean varieties under saturated soil culture and temporary flooding on tidal swamp. *Procedia Environmental Sciences* **33**, 87–93.

Goldsworthy, P.R., Palmer, A.F.E., and Sperling, D.W. (1974). Growth and yield of lowland tropical maize in Mexico. *The Journal of Agricultural Science* **83**, 223–230.

Gupta, N., Gaurav, S.S. and Kumar, A. (2013). Molecular basis of aluminium toxicity in plants: a review. *American Journal of Plant Sciences* **4**, 21–37.

Ismail, I.G., Adhi, W., Suwarno, Alihamsyah, and Herawati (1993). “Sewindu Penelitian Pertanian Di Lahan Rawa: Kontribusi dan Prospek Pengembangan”. Badan Litbang Pertanian, Jakarta (ID).

Jumakir and Endrizal. (2009). “Produktivitas Pertanaman Jagung di Lahan Pasang Surut Kabupaten Tanjung Jabung Barat Provinsi Jambi”. Seminar Nasional Serealia pp. 225–231. Balitserealia, Makasar (ID).

Kemenperin. (2016). “RI Impor Jagung 2.4 Juta Ton”. http://www.kemenperin.go.id/artikel/13892/2016,RIImporJagung2,4JutaTon [July 25, 2017]

Kementan. (2015). “Outlook Komoditas Pertanian Subsektor Tanaman Pangan”. Pusat Data dan Sistem Informasi Pertanian.

Komalasari, W.B. (2018). “Buletin Konsumsi Pangan”. Pusat Data dan Sistem Informasi Pertanian.

Lubis, I., Noor, A., Ghulamahdi, M., Chozin, M.A., Anwar, K., and Wirnas, D. (2016). Screening method for iron tolerant rice suited for tidal swamp area. *Journal of the International Society for Southeast Asian Agricultural Sciences* **22**, 30–41.

Marschner, P. (2012). “Mineral Nutrient on Higher Plants”. 3rd ed. Academic Press.

Nazemi, D., Hairani, A., and Nurita. (2012). Optimalisasi pemanfaatan lahan rawa pasang surut melalui pengelolaan lahan dan komoditas. *Agrovigor* **5**, 52–57.

Noya, A.I., Ghulamahdi, M., Sopandie, D., Sutandi, A., and Melati, M. (2014). Pengaruh kedalaman muka air dan amelioran terhadap produktivitas kedelai di lahan sulfat masam. *Pangan* **23**, 120–132.

Panda, S.K., Baluska, F., and Matsumoto, H. (2009). Aluminum stress signaling in plants. *Plant Signalling & Behavior* **4**, 592–597.

Ren, B., Zhang, J., Li, X., Fan, X., Dong, S., and Liu, P. (2014). Effects of waterlogging on the yield and growth of summer maize under field conditions. *Canadian Journal of Plant Sciences* **94**, 23–31.

Roberto, J., Souza, P. De, Guimarães, M.F. De, Lopes, M.M., and Henrique, C. (2000). Morphological alterations of corn (*Zea mays* L.) plants in response to aluminum toxicity in the soil. *Brazilian Archives of Biology and Technology* **43**.

Sagala, D. (2015). “Adaptation of Soybean Genotypes from Various Contries on Tidal Swamps in The Wet Tropical”. Thesis. Institut Pertanian Bogor.

Sairam, R.K., Kumutha, D., Ezhilmathi, K., Deshmukh, P.S., and Srivastava, G.C. (2008). Physiology and biochemistry of waterlogging tolerance in plants. *Biologia Plantarum* **52**, 401–412.

Sulistiyani, D.P. and Putra, A.G. (2014). Penilaian kualitas tanah pada lahan rawa pasang surut untuk tanaman jagung (*Zea mays* L.) di desa Banyu Urip kecamatan Tanjung Lago, kabupaten Banyuasin *In* “Prosiding Seminar Nasional Lahan Suboptimal 2014” pp 812–820. Palembang 26-27 September 2014.

Sutoro (2012). Kajian penyediaan varietas jagung untuk lahan suboptimal. *Iptek Tanaman Pangan* **7**, 108–115.

Suwandi. (2017). “Outlook Komoditas Subsektor Tanaman Pangan”. Pusat Data dan Sistem Informasi Pertanian.

Suwarti, Efendi, R., Azrai, M., and Thahir, N. (2013). Pertumbuhan, hasil dan indeks sensitivitas tanaman jagung terhadap cekaman genangan air *In* Seminar Nasional Serealia (M. Azrai, ed.) pp. 169–180. Balai Penelitian Tanaman Serealia, Maros.

Wang, X., Liu, T., Li, C., and Chen, H. (2012). Effects of soil flooding on photosynthesis and growth of *Zea mays* L . seedlings under different light intensities. *African Journal of Biotechnology* **11**, 7676–7683.

Xu, Z., and Zhou, G. (2008). Responses of leaf stomatal density to water status and its relationship with photosynthesis in a grass. *Journal of Experimental Botany* **59**, 3317–3325.