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DETERMINATION OF PLANTING TIME OF WATERMELON UNDER A SHALLOW GROUNDWATER TABLE IN TIDAL LOWLAND AGRICULTURE AREAS OF SOUTH SUMATRA, INDONESIA[†]

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ABSTRACT

[†] Étude sur la réponse des cultures de melon d'eau dans la nappe phréatique peu profonde à la croissance initiale pour la planification de la mise en valeur du drainage de l'agriculture des basses-terres des marées

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Watermelon cultivation is one of the proper alternatives in order to increase farmers' income from tidal lowland agriculture. Research of crop adaptation to wet soil conditions is required to enable farmers to decide the best planting time under various conditions within the existing land classification. The research to determine crop physiologic response during the initial growth period has been conducted in a greenhouse. This has been combined with field treatments based on groundwater table depths at 15, 10 and 5 cm-surface, respectively. Analysis of crop potential based on the water status conditions in the root zone was conducted by using secondary and primary data (daily records). Results of crop adaptation at shallow groundwater table depth showed that the treatments with groundwater table depth of 10 and 5 cm-surface were not significantly different in terms of plant height with magnitude of 12.6 and 12.3 cm, having 3 leaves. However, it had significant effect on root length with magnitude of 11.9 and 3.1 cm, respectively. Maximum plant height of 15.2 cm and 4 leaves was found for the treatment with groundwater table depth of 15 cm-surface. It can be concluded that farmers can best do planting at a groundwater table depth of 10 cm-surface.

KEY WORDS: tidal lowland; watermelon; groundwater table; drainage.

RÉSUMÉ

La culture de la pastèque est l'une des alternatives appropriées pour augmenter les revenus des agriculteurs issus de l'agriculture de marée basse. Des recherches sur l'adaptation des cultures aux conditions de sol humides sont nécessaires pour permettre aux agriculteurs de décider du meilleur moment de plantation dans diverses conditions dans la classification des terres existante. Les recherches visant à déterminer la réponse physiologique des cultures au cours de la période de croissance initiale ont été menées en serre. Ceci a été combiné avec des traitements sur le terrain basés sur la profondeur de la nappe phréatique à 15, 10 et 5 cm de surface respectivement. L'analyse du potentiel des cultures en fonction des conditions de l'état de l'eau dans la zone racinaire a été réalisée à l'aide de données secondaires et primaires (enregistrements quotidiens). Les résultats de l'adaptation des cultures à la profondeur de la nappe phréatique peu profonde ont montré que les traitements avec une profondeur de la nappe phréatique de 10 et 5 cm n'étaient pas significativement différents en termes de hauteur de 12,6 et 12,3 cm, avec 3 feuilles. Cependant, il a eu un effet significatif sur la longueur de la racine avec une magnitude de 11,9 et 3,1 cm, respectivement. Une hauteur de récolte maximale de 15,2 cm et 4 feuilles a été trouvée pour le traitement avec une profondeur de nappe phréatique de 15 cm de surface. On peut en conclure que les agriculteurs peuvent mieux planter à une profondeur de la nappe phréatique de 10 cm de surface.

MOTS CLÉS: plaine de marée; pastèque; nappe phréatique drainage.

INTRODUCTION

Tidal lowlands are low lying, flat coastal plains, with a micro relief of not more than 1.00 m (Schultz *et al*., 2013). Dependent on the relative position of the land to the tide, the following classification has been made by the Directorate of Swamps (1984). There are four hydro topographic classes:

- Class A is land below low high tide. The land can always get water from the tide during the dry and wet seasons;
- Class B is land below high tide, but above land in Class A. The land can only get tide water during the wet season;
- Class C is land not higher than 0.50 m above the highest tide. The water table is lower than 0.50 m-surface. Water supply from high tidal water cannot be provided because it is below the surface. Class C land is therefore highly dependent on rainfall;
- Class D is land above class C (upland soils). The land never receives water from the tide and is suitable for upland crops or plantations. The water table is deeper than 0.50 m-surface.

In the tidal lowland areas tertiary canals have the function to collect and discharge excess water during the wet season and if possible to supply fresh water during the dry season. When in these canals stop logs or flap gates have been installed improved water management with a focus on these functions can be established (Suprianto *et al*., 2010; Imanudin *et al*., 2016).

Agriculture in tidal lowland areas of Indonesia has faced the problem of land use conversion from food crops to plantation crops. One effort of controlling land use conversion in tidal lowland agriculture is to increase the planting intensity. Studies by Imanudin *et al.* (2010; 2011) in tidal lowland in the Telang II area showed that the land had high potential for two or even three crops per year (Schultz *et al*., 2015). The change of planting pattern from one into two times planting can bring equal income compared to the income from oil palm. The change of planting pattern from *rice-fallow* into *rice-corn* and *rice-corn-corn* was more profitable (Imanudin and Bakri, 2014). Crop diversification with watermelon provides new prospects for farmers because it can result in a higher income than compared to that of an oil palm plantation. The profit gained from watermelon cultivation with duration of 70 to 90 days can be as high as 30 million Rp/ha[1]. According to Gunawan (2014), if watermelon production is 11 tons and the price is 3000 Rp/kg, then the net profit received by the farmers is about 18.5 million Rp.

Watermelon cultivation is therefore one of the proper alternatives in order to increase farmers' income from tidal lowland agriculture. However, information related to the minimum depth of the groundwater table for crop planting is very important for farmers to determine the planting date. Therefore, research on crop adaptation to wet soil conditions was required to enable farmers to decide on the best planting time under various conditions within the existing land classification. This paper describes the experimental research of watermelon under greenhouse control conditions and validated by using groundwater data that have been recorded in the Telang area, South Sumatra.

BACKGROUND

The value of the benefit/cost (B/C) ratio is highly dependent on the cost of agricultural inputs. Research in Iran showed that there the B/C ratio of watermelon plants was 2.6 (Namdari, 2011). Adeoye *et al.* (2011) reported that the B/C ratios in Nigeria are lower at only 2.3 because of the costs for transportation and fertilizer. So far the largest watermelon producing country is China. However, Indonesia is among the top 20 countries exporting fruit (Food and Agriculture Organization of the United Nations (FAO), 2014) A watermelon cultivation effort in the lowlands is considered to be useful as an option for farm enterprise diversification.

Wang *et al.* (2004) reported that irrigation is needed for crop cultivation if rainfall during the growing season is less than 120 mm. They stated that 68 mm irrigation water will increase production by 46%. They also stated that irrigation water coupled with mulch can increase production with 11.4 ton/ha compared to the cultivation without mulch.

Evapotranspiration is strongly influenced by changes in groundwater depth. The closer groundwater is to the soil surface, the higher is the evapotranspiration. In lowland areas plant growth is highly dependent on water supply from capillary water movement. Results of a study by Singh *et al*. (2006) on *Typic Haplustalf* soil with a clay content of 45% showed capillary water movement of 18.7 mm/day at groundwater depth of 0.90 m-surface. The groundwater contribution decreased to 10.7 mm/day at groundwater depth of 1.20 m-surface. Results of a study by Singh *et al*. (2006) showed that the groundwater contribution was 10.7 mm/day if the groundwater table depth was 1.20 m-surface for dominated clay textural soil. On the other hand, the capillary water contribution was 4.8 mm/day if the groundwater table was at 0.74 m-surface and 2.5 mm/day if the groundwater table was at 1.00 m-surface for sandy loam soil (Udom *et al*., 2013). Groundwater contribution in sandy clay soil at a groundwater depth of 0.74 m-surface was 4.76 mm/day and 2.45 mm/day at groundwater depth of 1.00 m-surface (Udom *et al.*, 2013). These data showed that groundwater movement at 1.00-1.20 m-surface is sufficient to fulfil the evapotranspiration requirement. However, the crop will require addition of irrigation water if the groundwater is located deeper than 2.00 m-surface.

[1] Rp = Indonesian Rupiah, 1 Rp = 0.000077 US$, price level 2016

Therefore, the water retention function to keep the groundwater table at 1.00-1.30 m-surface is very important if farmers cultivate crops during the dry season. Karimova *at al*. (2014) reported for the case of loamy clay soil that a groundwater table at 1.50 m-surface resulted in a evapotranspiration of 47% and at 3 m-surface only of 23%. This finding showed that the crop required irrigation for maximum evapotranspiration at those positions. Reported by Pelletier *et al*. (2015) at groundwater depth of 0.60 m-surface, almost 70-80% irrigation water can be saved. According to Agele *et al.* (2015) the variation in the contribution of capillary water to groundwater storage is a function of the groundwater depth. A high capillary rise is obtained when the depth of the groundwater table is within the threshold of the capillary rise during the harvesting period and evapotranspiration can be entirely sourced from groundwater. The simulations conducted by Gao *et al*. (2017) suggest that at a groundwater depth of 1.00 m-surface 40% of the evapotranspiration from plants is supplied from capillary water.

Humphries and Wheeler (1963) stated that the number of leaves and the size were affected by genotype and environment. The leave position of a plant that is primarily controlled by genotype also has effect on leave growth rate, final size of leaves and better response capacity to environment, such as water availability. A crop which is capable to produce higher photosynthesis will produce more leaves because photosynthesis will be used to develop crop organs, such as leaves and trunk in accordance to the increase of crop dry matter weight (Hasanuddin *et al.,* 1996).

The ideal condition for crop growth is at an available water condition between field capacity and permanent wilting point. Crop growth at the initial phase will be disturbed if the soil moisture is at 75% level of exhausted available water, whereas optimum crop growth is at 50% level of exhausted available water (Modi and Zulu, 2012). A crop which is flooded during a short time will experience hypoxia (lack of O_2). Hypoxia usually occurs if part of the crop roots are flooded (crown part is not flooded) or when the crop is flooded for a long time but crop roots are located near the soil surface. If all parts of a crop are flooded, then the roots are located deeper in the soil and experience flooding for a longer time so that the crop is in anoxia condition (without O_2 environment). The anoxia condition occurs 6 to 8 hours after flooding because O_2 is suppressed by water and the rest of O_2 is utilized by microorganisms. The left over O_2 content within the soil during flooded conditions with a crop is used up faster because the O_2 diffusion rate within a wet soil is 10,000 times slower than the O_2 diffusion rate in air (Amstrong, 1979). Conditions of hypoxia or anoxia not only prevent N fixation, but also distribution of N and other minerals, which in turn impede root growth and nodulation. Leaves will experience yellowing followed by leave falling due to insufficient transportation of N and minerals into the crown part. Scott and Fisher (1989) reported that flooding effects were indicated by leave yellowing, leave falling at the lowest joint, dwarf and decrease of dry matter weight and crop yield. According to Hapsari and Adie (2010) results of their study on soybeans showed that yield losses at the vegetative phase were generally lower than during the reproductive phase, having values of respectively 17 to 43% and 50 to 56%. The magnitude of yield losses was dependent on crop variety, crop growth phase, flooding period, soil texture and the existence of crop weeds and diseases. According to Pasaribu *et al.* (2013), under tropical climatic conditions in *ultisol* soil crop water requirement for watermelon is 2.8 mm/day for the initial growth phase, 6.2 mm/day for middle growth phase and 4.4 mm/day for final growth phase, respectively.

Tidal lowland areas with a shallow groundwater table have a high potential for watermelon cultivation. The groundwater contribution through capillary flow is sufficient to provide the crop water requirement (Imanudin and Bakri, 2014). This condition has the advantage that irrigation is not needed, resulting in cost saving. Imanudin and Susanto (2010) stated that controlled drainage is the best option to maintain preferred water levels in lowland areas. Farmers would have to install hydraulic structures in tertiary canals in order to control the open water table on levels in such a way that optimal growth conditions for the crops are created. However, if planting is delayed at flowering stage during the dry season and the groundwater depth exceeds 1.50 m-surface, irrigation by pumping needs to be provided (Singh *et al.,* 2006). In addition, a long period of flooding results in abiotic stress of the crop, which affects the sprout growth rate, seed development and subsequently affects crop growth and development, especially during the initial growth period (Dat *el al.,* 2000). The food crop is capable to tolerate a water content level which exceeds the field capacity with 25% (Prawoto *et al.,* 2005).

In the Telang area during the November-January period the water is generally above the soil surface with a 10-20 cm inundation height. In this period the rice is planted (first season), Entering at February the water level is gradually lowered to a depth of 20-30 cm-surface and the rice reaches the harvest period (Imanudin *et al*., 2014). According to Bakri *et al*. (2014) the groundwater levels after the rice harvesting are still high enough for the cultivation of a second crop. If there are tertiary gates then they will be operated to achieve maximum drainage. In the March-April period, groundwater levels in tidal lowlands that have a Class B hydro topography are in the range of 20-30 cm-surface. Thus the soil moisture in the root zone is still too wet for a second crop like corn. However watermelon plants could be planted by the end of April.

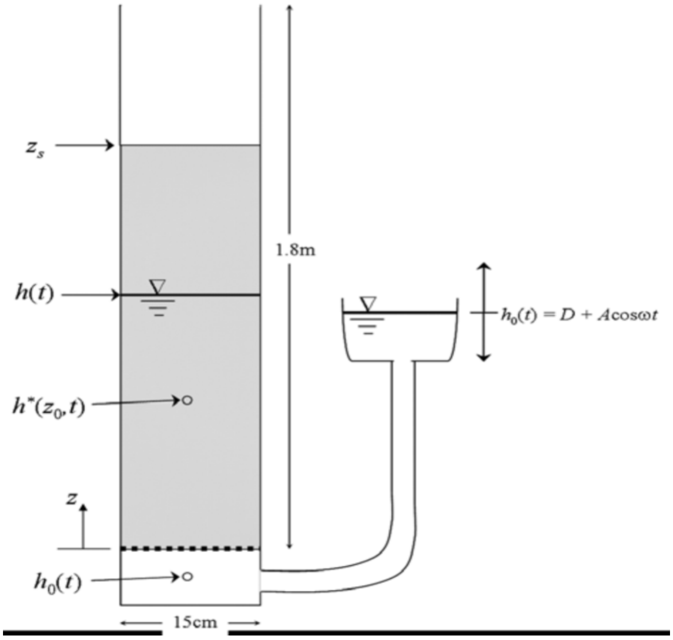
Based on the above discussion, applied research was considered to be required to determine watermelon crop response at the initial phase to shallow groundwater table conditions.

MATERIALS AND METHODS

The research was conducted from March to April 2016 in the greenhouse at the Agroecotechnology Department, Faculty of Agriculture, Sriwijaya University. Data of daily groundwater level from secondary data and direct observations were used to analyse the planting time. The secondary data were obtained at tidal lowland pilot project areas in the Telang I area. The direct observations were done at a tertiary plot in the Telang II area in 2015 (Imanudin *et al.*, 2010).

Materials and equipment used in this study were soil, having a sandy loam texture, watermelon seeds, water and aqua bottles. Equipment for groundwater level control was obtained by using the continuous flow system (Figure 1) in which the groundwater level is kept in equilibrium with the groundwater level in a reservoir using the principle of connected vessel. The exprimental application of groundwater depth to supply irrigation by capillary rise is presented in Figure 2. Treatments consisted of maintaining groundwater depth at 5, 10 and 15 cm-surface. In order to maintain a constant groundwater level, the water height in the column was kept constant, which required daily observation. Crop growth was determined by measuring height as well as number of leaves at two weeks after planting. Root length and number of leaves for each treatment have also been observed at the end of the experiment.

To determine the best planting in the field, daily groundwater data were analysed by comparing the greenhouse experimental result of watermelon growth response to shallow groundwater tables in the initial phase. Data analysis of the daily groundwater level was done to determine planting potential in the field. The data of daily groundwater level have also been compared with rainfall data in 2015 that were obtained from Kenten Climatologic Station in Palembang.



Zs = soil surface
h(t) = water table at soil column
h(z0,t) = water table zone
ho(t) = water column

ɔution to crop water requirement

Figure 2. Exprimental application of groundwater depth to supply irrigation water to the crop

RESULTS AND DISCUSSION

Study of planting potential in tidal lowland area

Watermelon cultivation in tidal lowland areas is highly dependent on the season. Planting in the wet season cannot be implemented due to the very high groundwater level as a result of the rainfall. Figure 3 shows groundwater level observations in the Telang I area in 2009, which indicate that the groundwater was too saturated up to May for cultivation of crops, except for rice. Planting could be done by the end of May or early June with as a consequence that the crops frequently experienced dryness during the generative phase in August.

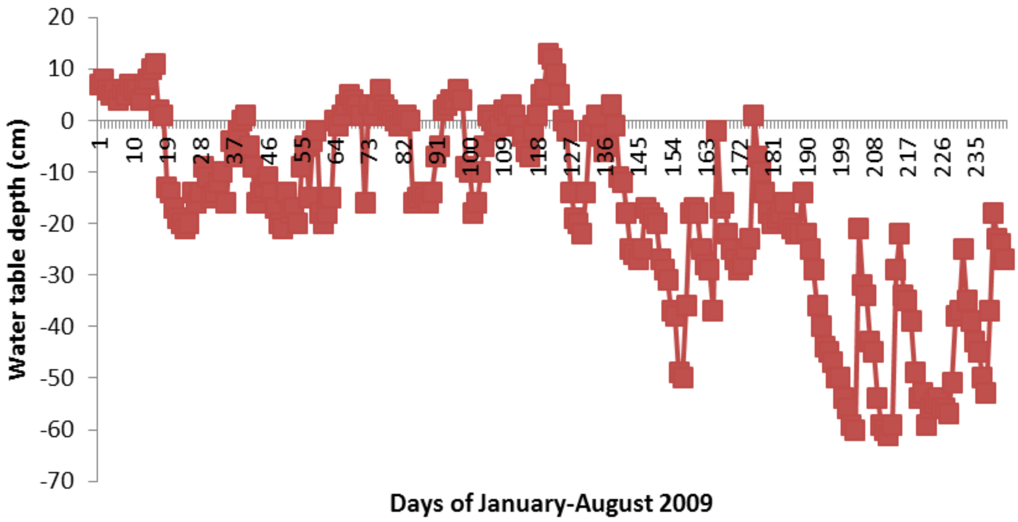


Figure 3. Groundwater level during the January-August period at normal conditions (Imanudin *et al*., 2010)

When structures in the tertiary canals have been installed then according to Bakri *et al.* (2015) the water management objective for crop cultivation in the period June-September will be water retention within the tertiary canals. If high fresh tidal water still can enter the tertiary canal, then a proper water gate is a stop log with a retention level of 0.50 m from the bottom level of the canal. The stop log height would have to be regulated such that high tidal water can enter the canal and water is held at a minimum of 0.50 m-surface during the low tide period. If an automatic fibre flap gate has been installed, then the gate position during the dry season needs to be before the culvert at the downstream side of the tertiary canal so that high tidal water can enter the canal and the gate will automatically close during the low tide period. However, such gates can easily be damaged and cannot be repaired by the farmers (Imanudin *et al.*, 2016).

Although in November high tidal water can be blocked to prevent it from entering the land, high rainfall intensity coupled with insufficient duration of low tide for discharge will result in full canals and difficulty of achieving groundwater drawdown. Figure 4 shows data of groundwater level fluctuation from February to March at Class B land in 2015. The drastic upward movement of the groundwater level was due to rainfall. At the time that there were no structures and the tide water could enter the tertiary block the land had more excess water and a higher groundwater level or inundation during the wet season. The groundwater level continuously dropped in case of no rainfall. In addition to the structures in the tertiary canals, in the concerned area a micro water management system has been installed. The system consists of small canals (called *micro channel*) at 8 m spacing, having a depth of 20 cm. The data in Figure 9 show that the micro water management system was relatively effective in lowering of the groundwater level. However, farmers could not do planting in early March because the average depth of the groundwater level was less than 10 cm- surface. Figure 3 also shows that there was flooding for 10 to 12 days. Direct planting of watermelon seeds could not be done in this condition and could only be done at the 14th day or in the middle of March.

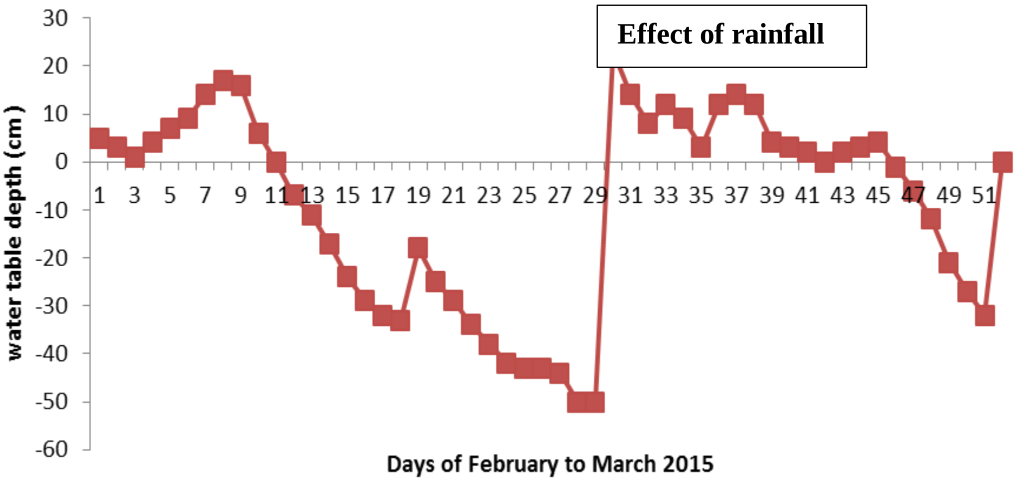


Figure 4. Groundwater level in February and March 2015 under dry conditions

Planting would have to be done at the end of the wet season in April or as a result of the El Nino effect in 2015 even in March due to the dry conditions. Crop adaptation to dry conditions could start planting in the early growth period in the wet season. The decision to move the planting time forward was made to prevent water deficiency during the generative growth phase. Dry climate conditions in August-September cause a moisture content in the root zone close to the permanent wilting point due to the decrease of the capillary rise, because the groundwater dropped deeper than 1.50 m-surface. Rainfall started to decrease at the beginning of July and the maximum decrease occurred in the period August-October (Figure 5).

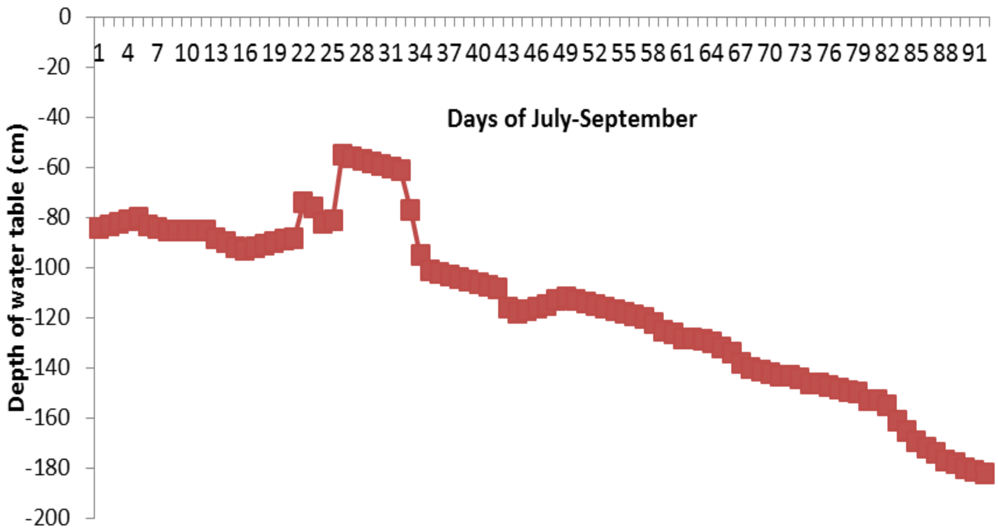


Figure 5. Groundwater level during the dry season of 2015 in Class B land

Planting intensity can be done two or even three times as an impact of land and water management. In addition, intensive farming can decrease forest and land fire indirectly if the land is properly managed and utilized (Imanudin and Susanto, 2015).

Experiment of watermelon planting under shallow groundwater table conditions

The basic objective of the experiment was to analyse the possibilities for earlier planting of watermelon during the wet season in March or early April. For that reason the experiment was done in a greenhouse to identify the crop response to shallow groundwater table conditions.

Crop testing results for two groundwater conditions mentioned above showed that the crop can still grow at groundwater depth of 5 cm-surface with under optimal growth level. Watermelon had already growth at the 4th day for groundwater depth of 10 cm-surface, but it did not grow yet for the groundwater depth of 5 cm-surface. Plant height was 5.6 cm and the leaves were still cringe (closed) with uplifted seed skin at the 6th day for the groundwater depth of 10 cm-surface, but stem prospective was just emerging for groundwater depth of 10 cm-surface. Plant height was 12.1 cm with 3 leaves at the 17th day for groundwater depth of 10 cm-surface, whereas it was 8.2 cm with 3 leaves at the 17th day for groundwater depth of 5 cm-surface. Average growth rate of the crop until the 17th day for groundwater depth of 10 cm-surface was 0.71 cm/day and its value was 0.48 cm/day for groundwater depth of 5 cm-surface. Crop growth description can be seen in Figure 6.

-5 cm -10 cm -15 cm

Figure 6. Visualization of watermelon response to shallow groundwater table conditions (15th day).

The laboratory experiment was stopped 20 days of after planting because it was estimated that the groundwater had dropped more than 20 cm-surface at field conditions. This period was at the end of the wet season (April) when farmers did planting at the end of March. The plant can be more adaptive to environment conditions during this period. Observations at the 20th day were conducted on watermelon treated with a groundwater table at 15 cm-surface. Plant height was 15.2 cm and it had 4 leaves. The plants had more leaves at this treatment than that the plants of the 10 and 5 cm-surface treatments.

Average plant height was 0.76 cm for the 15 cm-surface treatment. This value was relatively similar to the result obtained from 10 cm-surface. Therefore, watermelon cultivation can be started if field conditions show a groundwater level of 10 cm-surface. The contrast condition was found with the 5 cm-surface treatment, which showed stopping of the growth of root elongation. The root length was only 3.1 cm at 20 days after planting, which indicated that root growth avoids a high groundwater table.

Potential time of planting at Class C land

Results from greenhouse experiments also showed that watermelon can be planted under conditions of a shallow groundwater table between 10 and 15 cm-surface, if watermelon is cultivated at Class C land. The water in the tertiary canals can maintain the groundwater table. In tidal lowland areas, then the planting time can be accelerated to the end of February or planting can be directly conducted after rice harvesting. Planting can be done by using the hole system in which after clearance of rice straw a micro canal is being dug at every 6 to 8 m, using single plough equipment. The planting needs to be done quickly in order to prevent dryness. If planting is done at the end of February or in early March harvesting can be expected by the end of May. The generative phase would be in May. Observation results of the groundwater level fluctuation showed that planting could be done early March when the groundwater level was 20 to 30 cm-surface (Land and Water Management Tidal Lowlands (LWMTL), 2006). Dependent on the groundwater level planting could be done in February, but it is better to do it early March, because in February farmers are busy with first season rice harvesting. Water retention in canals needs to be provided in order to maintain a groundwater table close to the root zone.

The flowering phase in May poses a high risk, because the groundwater table frequently drops to 0.90 - 1.00 m-surface (Figure 7). Therefore, irrigation would be needed in this phase for at least two times application. Irrigation by pumps would be helpful to pump water from tertiary canals using furrow irrigation. High soil porosity in Class C land may cause that capillary water is not sufficiently available to fulfil the evapotranspiration requirement if the depth of the groundwater table is lower than 1.00 m-surface. This showed that the critical level of the groundwater table is at 1.00 m-surface for Class C land, whereas the critical level of the groundwater table is at 1.50 m-surface for Class B land, when dominated by clay soil. Analysis results of groundwater table fluctuation showed that watermelon cultivation can be done without irrigation in Class B land (Figure 8).

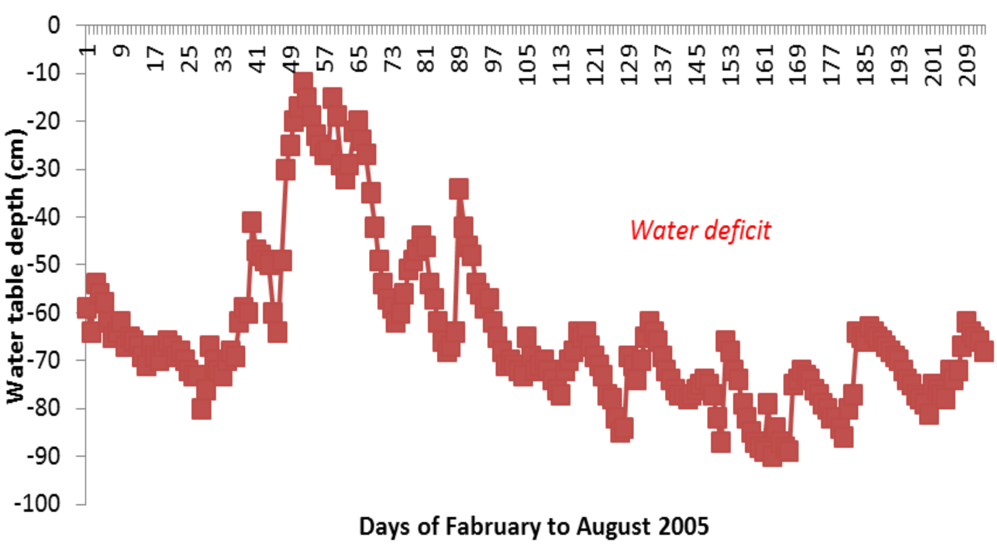


Figure 7. Groundwater table fluctuation at Class C tidal lowland area (LWMTL, 2006)

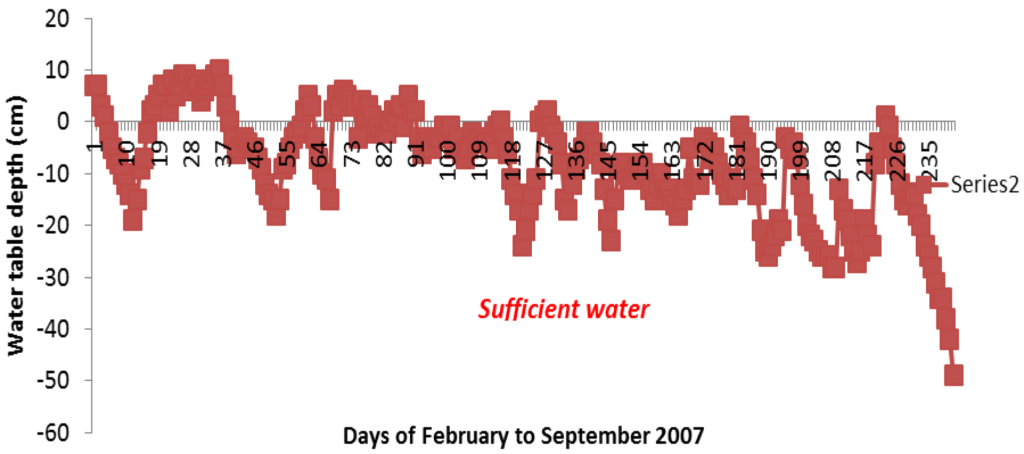


Figure 8. Groundwater fluctuation at Class B land (Imanudin *et al.,* 2010)

CONCLUSIONS

The following conclusions can be drawn from this study:

- Watermelon has the potential to be developed in tidal lowland areas because it is relatively tolerant to shallow groundwater depth in the initial growth phase. The crop was capable to grow at a groundwater depth of 5 cm-surface. Optimum growth was achieved at a groundwater depth of 15 cm-surface. However, field application showed that watermelon can be planted at a groundwater depth of 10 cm-surface. Results of the field study showed that a groundwater depth for Class B-C land had reached 15 cm-surface in March-April. Accelerated planting at the end of March is important in order to prevent dryness during the generative phase, when irrigation by gravity cannot be applied;
- crop adaptation to the groundwater table is depending on the planting time and land category. The crop could be planted in June and was harvested in September without irrigation in Class A and B lands. Capillary water at these land classes was sufficient to fulfil the evapotranspiration requirement. However, an earlier planting time in March and harvesting in May-June needs to be conducted at the Class C land, because this land had a high soil porosity. Capillary water during the dry season in this soil could not fulfil the evapotranspiration requirement. In June-September the groundwater could reach more than 1.20 m-surface;
- the tertiary canal needs to be equipped with a stop log, or flap gate to control the preferred groundwater table. The main option for Class A and B land was drainage, whereas for Class C land it was water retention.

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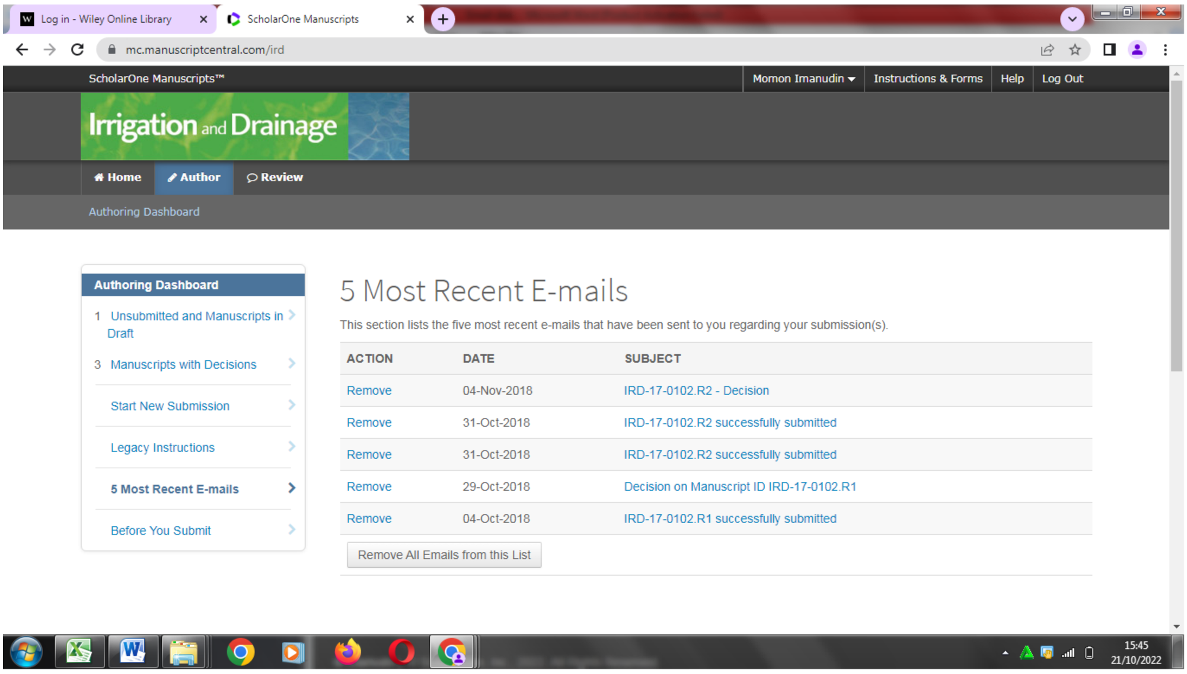

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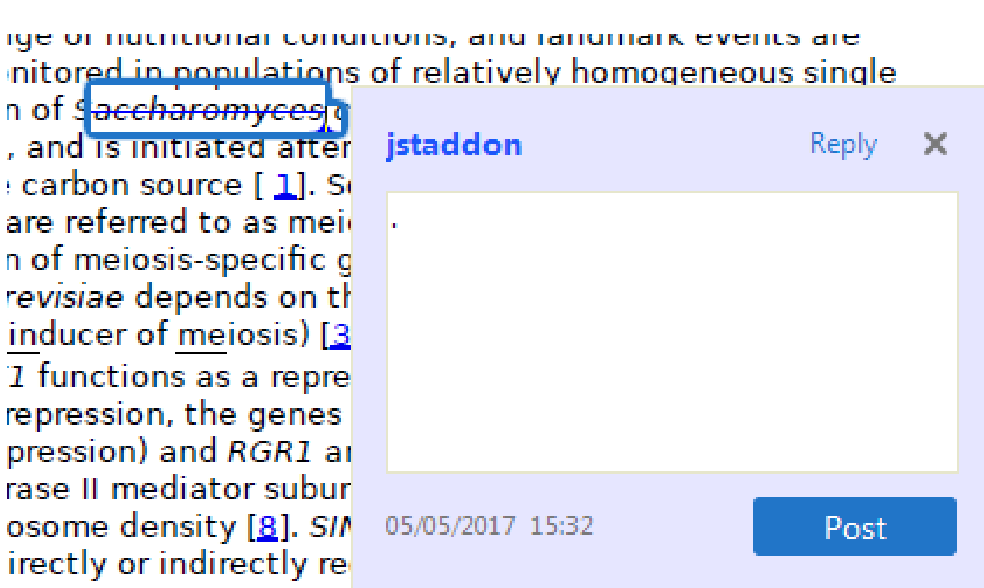

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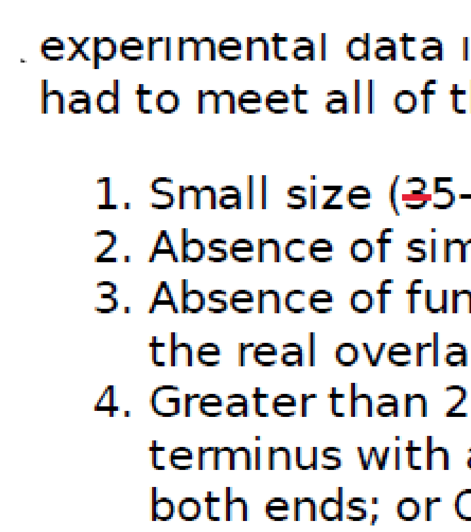

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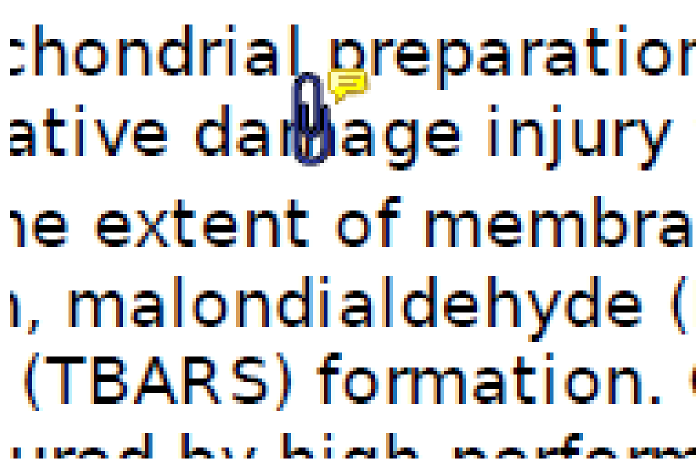

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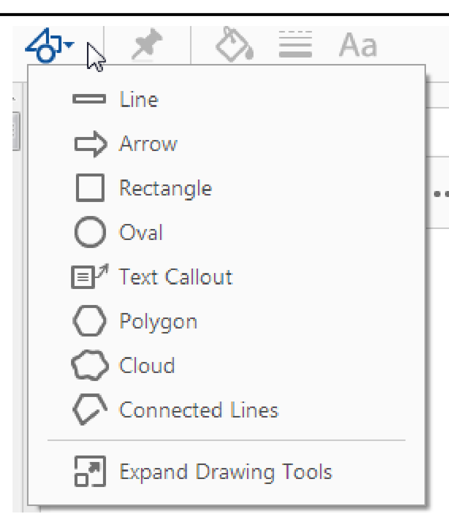

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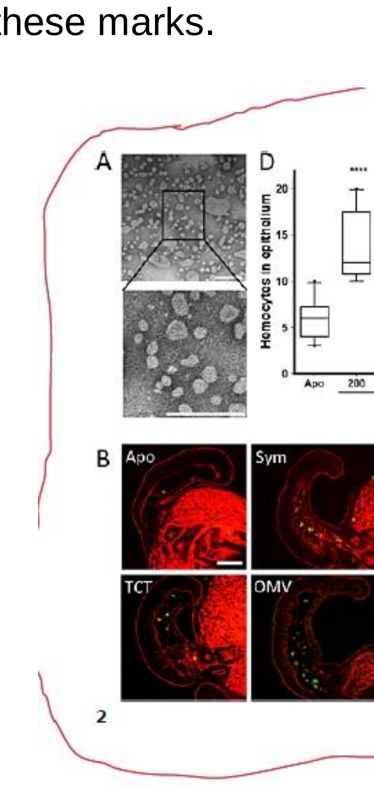

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DETERMINATION OF PLANTING TIME OF WATERMELON UNDER A SHALLOW GROUNDWATER TABLE IN TIDAL LOWLAND AGRICULTURE AREAS OF SOUTH SUMATRA, INDONESIA†

MOMON SODIK IMANUDIN*, M.E. ARMANTO AND BAKRI

Department of Soil Science, Faculty of Agriculture, Sriwijaya University, Palembang, Indonesia

ABSTRACT

Watermelon cultivation is one of the appropriate alternatives in order to increase farmers' income from tidal lowland agriculture. Research into crop adaptation to wet soil conditions is required to enable farmers to decide the best planting time under various conditions within the existing land classification. The research to determine crop physiological response during the initial growth period was conducted in a greenhouse. This was combined with field treatments based on groundwater table depths at 15, 10 and 5 cm-surface, respectively. Analysis of crop potential based on the water status conditions in the root zone was conducted by using secondary and primary data (daily records). Results of crop adaptation at shallow groundwater table depth showed that the treatments with groundwater table depth of 10 and 5 cm-surface were not significantly different in terms of plant height, with a size of 12.6 and 12.3 cm, having three leaves. However, it had a significant effect on root length, with a length of 11.9 and 3.1 cm, respectively. Maximum plant height of 15.2 cm and four leaves were found for the treatment with a groundwater table depth of 15 cm-surface. It may be concluded that it is best for farmers to plant at a groundwater table depth of 10 cm-surface. © 2019 John Wiley & Sons, Ltd.

key words: tidal lowland; watermelon; groundwater table; drainage

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RÉSUMÉ

La culture de la pastèque est l'une des alternatives appropriées pour augmenter les revenus des agriculteurs issus de l'agriculture des plaines de marée. Des recherches sur l'adaptation des cultures aux conditions de sol humides sont nécessaires pour permettre aux agriculteurs de décider du meilleur moment de plantation dans diverses conditions dans la classification des terres existante. Les recherches visant à déterminer la réponse physiologique des cultures au cours de la période de croissance initiale ont été menées en serre. Ceci a été combiné avec des traitements sur le terrain basés sur la profondeur de la nappe phréatique à 15, 10 et 5 cm de surface respectivement. L'analyse du potentiel des cultures en fonction des conditions de l'état de l'eau dans la zone racinaire a été réalisée à l'aide de données secondaires et primaires (enregistrements quotidiens). Les résultats de l'adaptation des cultures à la profondeur de la nappe phréatique peu profonde ont montré que les traitements avec une profondeur de la nappe phréatique de 10 et 5 cm n'étaient pas significativement différents en termes de hauteur de plants de 12,6 et 12,3 cm, avec trois feuilles. Cependant, il a eu un effet significatif sur la longueur de la racine avec une magnitude de 11,9 et 3,1 cm, respectivement. Une hauteur de plant maximale de 15,2 cm et quatre feuilles a été trouvée pour le traitement avec une profondeur de nappe phréatique de 15 cm. On peut en conclure que les agriculteurs peuvent mieux planter à une profondeur de la nappe phréatique de 10 cm. © 2019 John Wiley & Sons, Ltd.

mots clés: plaine de marée; pastèque; nappe phréatique; drainage

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†Détermination de la date de plantation de pastèques en agriculture sous nappe phréatique peu profonde des plaines de marées.

Contract/grant sponsor: Hibah Bersaing (Grand competition) research grant of Ministry of Research, Technology and Higher Education of Indonesia Republic; contract/grant number: 383/UN9.3.1/LT/2016

INTRODUCTION

Tidal lowlands are low lying, flat coastal plains, with a micro relief of not more than 1.00 m (Schultz *et al*., 2013). Dependent on the relative position of the land to the tide, the following classification has been made by the Directorate of Swamps (1984). There are four hydro topographic classes:

- Class A is land below low high tide. The land can always get water from the tide during the dry and wet seasons;
- Class B is land below high tide, but above land in Class A. The land can only get tide water during the wet season;
- Class C is land not higher than 0.50 m above the highest tide. The water table is lower than 0.50 m-surface. Water supply from high tidal water cannot be provided because it is below the surface. Class C land is therefore highly dependent on rainfall;
- Class D is land above class C (upland soils). The land never receives water from the tide and is suitable for upland crops or plantations. The water table is deeper than 0.50 m-surface.

In the tidal lowland areas tertiary canals have the function to collect and discharge excess water during the wet season and if possible to supply fresh water during the dry season. When in these canals stop logs or flap gates have been installed improved water management with a focus on these functions can be established (Suprianto *et al*., 2010; Imanudin *et al*., 2016).

Agriculture in tidal lowland areas of Indonesia has faced the problem of land use conversion from food crops to plantation crops. One effort of controlling land use conversion in tidal lowland agriculture is to increase the planting intensity. Studies by Imanudin *et al.* (2010; 2011) in tidal lowland in the Telang II area showed that the land had high potential for two or even three crops per year (Schultz *et al*., 2015). The change of planting pattern from one into two times planting can bring equal income compared to the income from oil palm. The change of planting pattern from *rice-fallow* into *rice-corn* and *rice-corn-corn* was more profitable (Imanudin and Bakri, 2014). Crop diversification with watermelon provides new prospects for farmers because it can result in a higher income than compared to that of an oil palm plantation. The profit gained from watermelon cultivation with duration of 70 to 90 days can be as high as 30 million Rp/ha[1]. According to Gunawan (2014), if watermelon production is 11 tons and the price is 3000 Rp/kg, then the net profit received by the farmers is about 18.5 million Rp.

Watermelon cultivation is therefore one of the proper alternatives in order to increase farmers' income

[1] Rp = Indonesian Rupiah, 1 Rp = 0.000077 US$, price level 2016

from tidal lowland agriculture. However, information related to the minimum depth of the groundwater table for crop planting is very important for farmers to determine the planting date. Therefore, research on crop adaptation to wet soil conditions was required to enable farmers to decide on the best planting time under various conditions within the existing land classification. This paper describes the experimental research of watermelon under greenhouse control conditions and validated by using groundwater data that have been recorded in the Telang area, South Sumatra.

BACKGROUND

The value of the benefit/cost (B/C) ratio is highly dependent on the cost of agricultural inputs. Research in Iran showed that there the B/C ratio of watermelon plants was 2.6 (Namdari, 2011). Adeboye *et al*. (2011) reported that the B/C ratios in Nigeria are lower at only 2.3 because of the costs of transportation and fertilizer. At present the larg- est watermelon-producing country is China. However, Indonesia is among the top 20 countries exporting the fruit (World Atlas, 2019). A watermelon cultivation effort in the low- lands is considered to be useful as an option for farm enter- prize diversification.

Wang *et al*. (2017) reported that irrigation is needed for crop cultivation if rainfall during the growing season is less than 120 mm. They stated that 68 mm irrigation water will increase production by 46%. They also stated that irrigation water coupled with mulch can increase production with 11.4 ton/ha compared to the cultivation without mulch.

Evapotranspiration is strongly influenced by changes in groundwater depth. The closer groundwater is to the soil surface, the higher is the evapotranspiration. In lowland areas plant growth is highly dependent on water supply from capillary water movement. Results of a study by Singh *et al*. (2006) on *Typic Haplustalf* soil with a clay content of 45% showed capillary water movement of 18.7 mm/day at groundwater depth of 0.90 m-surface. The groundwater contribution decreased to 10.7 mm/day at groundwater depth of 1.20 m-surface. Results of a study by Singh *et al*. (2006) showed that the groundwater contribution was 10.7 mm/day if the groundwater table depth was 1.20 m-surface for dominated clay textural soil. On the other hand, the capillary water contribution was 4.8 mm/day if the groundwater table was at 0.74 m-surface and 2.5 mm/day if the groundwater table was at 1.00 m-surface for sandy loam soil (Udom *et al*., 2013). Groundwater contribution in sandy clay soil at a groundwater depth of 0.74 m-surface was 4.76 mm/day and 2.45 mm/day at groundwater depth of 1.00 m-surface (Udom *et al.*, 2013). These data showed that groundwater movement at 1.00-1.20 m-surface is sufficient to fulfil the evapotranspiration requirement. However, the crop will require addition of irrigation water if the groundwater is located deeper than 2.00 m-surface. Therefore, the water retention function to keep the groundwater table at 1.00-1.30 m-surface is very important if farmers cultivate crops during the dry season. Karimova *at al*. (2014) reported for the case of loamy clay soil that a groundwater table at 1.50 m-surface resulted in a evapotranspiration of 47% and at 3 m-surface only of 23%. This finding showed that the crop required irrigation for maximum evapotranspiration at those positions. Reported by Pelletier *et al*. (2015) at groundwater depth of 0.60 m-surface, almost 70-80% irrigation water can be saved. According to Agele *et al.* (2015) the variation in the contribution of capillary water to groundwater storage is a function of the groundwater depth. A high capillary rise is obtained when the depth of the groundwater table is within the threshold of the capillary rise during the harvesting period and evapotranspiration can be entirely sourced from groundwater. The simulations conducted by Gao et al., (2017) suggest that at a groundwater depth of 1.00 m-surface 40% of the evapotranspiration from plants is supplied from capillary water. Reported by Saraiva et al., (2018) to reduce water requirements in watermelon cultivation, mulch technology was successfully applied. Through that technology the production of watermelon reaches 73.66 Mg ha^{-1} with an irrigation water level of 314 mm.

The ideal condition for crop growth is at an available water condition between field capacity and permanent wilting point. Crop growth at the initial phase will be disturbed if the soil moisture is at 75% level of exhausted available water, whereas optimum crop growth is at 50% level of exhausted available water (Modi and Zulu, 2012). A crop which is flooded during a short time will experience hypoxia (lack of O_2). Hypoxia usually occurs if part of the crop roots are flooded (crown part is not flooded) or when the crop is flooded for a long time but crop roots are located near the soil surface. If all parts of a crop are flooded, then the roots are located deeper in the soil and experience flooding for a longer time so that the crop is in anoxia condition (without O_2 environment). The anoxia condition occurs 6 to 8 hours after flooding because O_2 is suppressed by water and the rest of O_2 is utilized by microorganisms. The left over O_2 content within the soil during flooded conditions with a crop is used up faster because the O_2 diffusion rate within a wet soil is 10,000 times slower than the O_2 diffusion rate in air (Amstrong, 1979). Conditions of hypoxia or anoxia not only prevent N fixation, but also distribution of N and other minerals, which in turn impede root growth and nodulation. Leaves will experience yellowing followed by leave falling due to insufficient transportation of N and minerals into the crown part. Scott and Fisher (1989) reported that flooding effects were indicated by leave yellowing, leave falling at the lowest joint, dwarf growth and decrease of dry matter weight and crop yield. According to Hapsari and Adie (2010) results of their study on soybeans showed that yield losses at the vegetative phase were generally lower than during the reproductive phase, having values of respectively 17 to 43% and 50 to 56%. The magnitude of yield losses was dependent on crop variety, crop growth phase, flooding period, soil texture and the existence of crop weeds and diseases. According to Pasaribu *et al.* (2013), under tropical climatic conditions in *ultisol* soil crop water requirement for watermelon is 2.8 mm/day for the initial growth phase, 6.2 mm/day for middle growth phase and 4.4 mm/day for final growth phase, respectively.

Tidal lowland areas with a shallow groundwater table have a high potential for watermelon cultivation. The groundwater contribution through capillary flow is sufficient to provide the crop water requirement (Imanudin and Bakri, 2014). This condition has the advantage that irrigation is not needed, resulting in cost saving. Imanudin et al., (2010) stated that controlled drainage is the best option to maintain preferred water levels in lowland areas. Farmers would have to install hydraulic structures in tertiary canals in order to control the open water table on levels in such a way that optimal growth conditions for the crops are created. However, if planting is delayed at flowering stage during the dry season and the groundwater depth exceeds 1.50 m-surface, irrigation by pumping needs to be provided (Singh *et al.*, 2006). In addition, a long period of flooding results in abiotic stress of the crop, which affects the sprout growth rate, seed development and subsequently affects crop growth and development, especially during the initial growth period (Dat el al., 2000). The food crop is capable to tolerate a water content level which exceeds the field capacity with 25% (Prawoto et al., 2005).

In the Telang area during the November-January period the water is generally above the soil surface with a 10-20 cm inundation height. In this period the rice is planted (first season), starting in February the water level on tertiary block was gradually lowered to a depth of 20-30 cm-surface and the rice reaches the harvest period (Imanudin and Bakri, 2014). According to Bakri *et al*. (2014) the groundwater levels after the rice harvesting are still high enough for the cultivation of a second crop. If there are tertiary gates then they will be operated to achieve maximum drainage. In the March-April period, groundwater levels in tidal lowlands that have a Class B hydro topography are in the range of 20-30 cm-surface. Thus the soil moisture in the root zone is still too wet for a second crop like corn. However watermelon plants could be planted by the end of April.

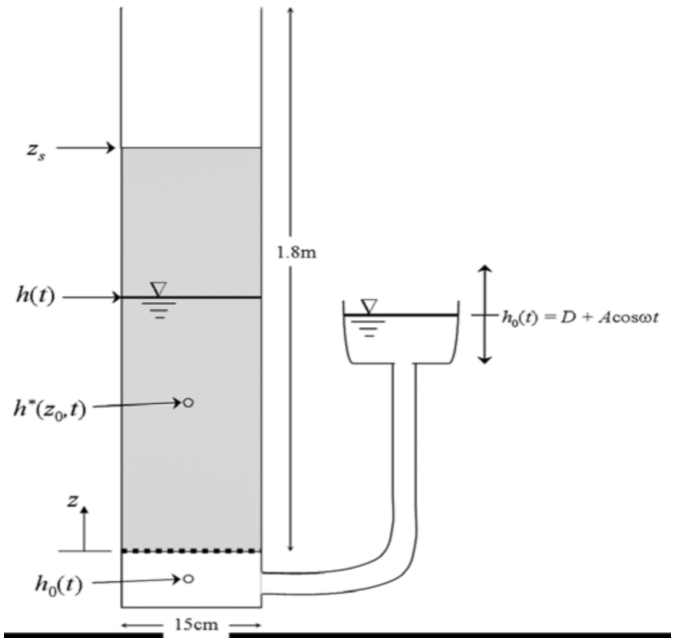
Based on the above discussion, applied research was considered to be required to determine watermelon crop response at the initial phase to shallow groundwater table conditions.

MATERIALS AND METHODS

The research was conducted from March to April 2016 in the greenhouse at the Agroecotechnology Department, Faculty of Agriculture, Sriwijaya University. Data of daily groundwater level from secondary data and direct observations were used to analyse the planting time. The secondary data were obtained at tidal lowland pilot project areas in the Telang I area. The direct observations were done at a tertiary plot in the Telang II area in 2015 (Imanudin *et al.*, 2010).

Materials and equipment used in this study were soil, having a sandy loam texture, watermelon seeds, water and aqua bottles. Equipment for groundwater level control was obtained by using the continuous flow system (Figure 1) in which the groundwater level is kept in equilibrium with the groundwater level in a reservoir using the principle of connected vessel. The exprimental application of groundwater depth to supply irrigation by capillary rise is presented in Figure 2. Treatments consisted of maintaining groundwater depth at 5, 10 and 15 cm-surface. In order to maintain a constant groundwater level, the water height in the column was kept constant, which required daily observation. Crop growth was determined by measuring height as well as number of leaves at two weeks after planting. Root length and number of leaves for each treatment have also been observed at the end of the experiment.

To determine the best planting in the field, daily groundwater data were analysed by comparing the greenhouse experimental result of watermelon growth response to shallow groundwater tables in the initial phase. Data analysis of the daily groundwater level was done to determine planting potential in the field. The data of daily groundwater level have also been compared with rainfall data in 2015 that were obtained from Kenten Climatologic Station in Palembang.



Zs = soil surface
h(t) = water table at soil column
h(z0,t) = water table zone
ho(t) = water column

Figure 1. Experimental set up of groundwater contribution to crop water requirement (Udom *et al*., 2013)

Figure 2. Exprimental application of groundwater depth to supply irrigation water to the crop

RESULTS AND DISCUSSION

Study of planting potential in tidal lowland area

Watermelon cultivation in tidal lowland areas is highly dependent on the season. Planting in the wet season cannot be implemented due to the very high groundwater level as a result of the rainfall. Figure 3 shows groundwater level observations in the Telang I area in 2009, which indicate that the groundwater was too saturated up to May for cultivation of crops, except for rice. Planting could be done by the end of May or early June with as a consequence that the crops frequently experienced dryness during the generative phase in August.

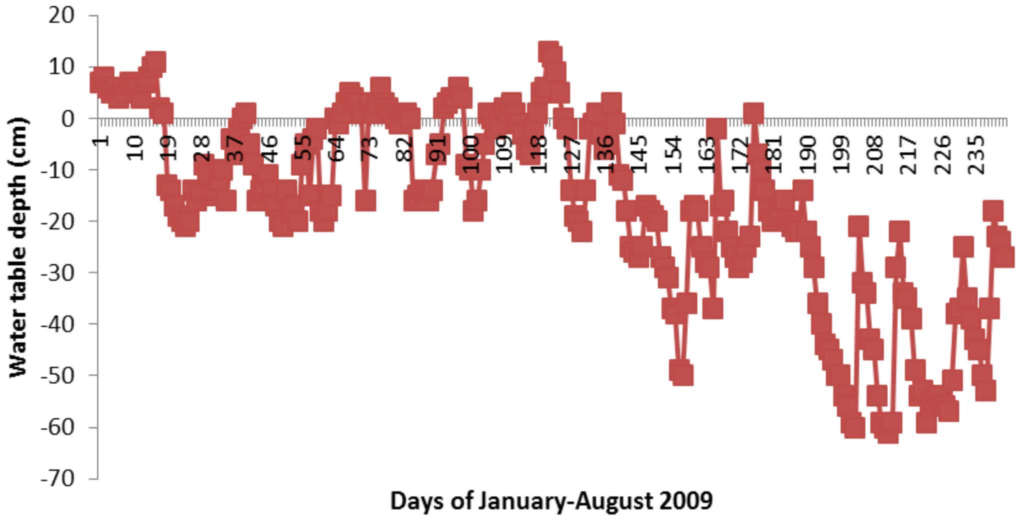


Figure 3. Groundwater level during the January-August period at normal conditions (Imanudin *et al.*, 2010)

When structures in the tertiary canals have been installed then according to Bakri *et al.* (2015) the water management objective for crop cultivation in the period June-September will be water retention within the tertiary canals. If high fresh tidal water still can enter the tertiary canal, then a proper water gate is a stop log with a retention level of 0.50 m from the bottom level of the canal. The stop log height would have to be regulated such that high tidal water can enter the canal and water is held at a minimum of 0.50 m-surface during the low tide period. If an automatic fibre flap gate has been installed, then the gate position during the dry season needs to be before the culvert at the downstream side of the tertiary canal so that high tidal water can enter the canal and the gate will automatically close during the low tide period. However, such gates can easily be damaged and cannot be repaired by the farmers (Imanudin *et al.*, 2016).

Although in November high tidal water can be blocked to prevent it from entering the land, high rainfall intensity coupled with insufficient duration of low tide for discharge will result in full canals and difficulty of achieving groundwater drawdown. Figure 4 shows data of groundwater level fluctuation from February to March at Class B land in 2015. The drastic upward movement of the groundwater level was due to rainfall. At the time that there were no structures and the tide water could enter the tertiary block the land had more excess water and a higher groundwater level or inundation during the wet season. The groundwater level continuously dropped in case of no rainfall. In addition to the structures in the tertiary canals, in the concerned area a micro water management system has been installed. The system consists of small canals (called *micro channel*) at 8 m spacing, having a depth of 20 cm. The data in Figure 4 show that the micro water management system was relatively effective in lowering of the groundwater level.

However, farmers could not do planting in early March because the average depth of the groundwater level was less than 10 cm- surface. Figure 3 also shows that there was flooding for 10 to 12 days. Direct planting of watermelon seeds could not be done in this condition and could only be done at the 14th day or in the middle of March.

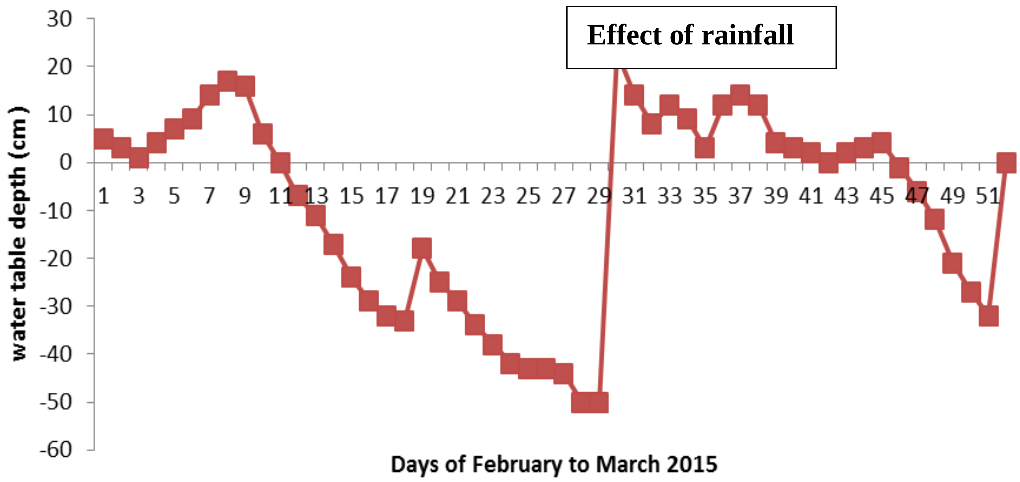


Figure 4. Groundwater level in February and March 2015 under dry conditions

Planting would have to be done at the end of the wet season in April or as a result of the El Nino effect in 2015 even in March due to the dry conditions. Crop adaptation to dry conditions could start planting in the early growth period in the wet season. The decision to move the planting time forward was made to prevent water deficiency during the generative growth phase. Dry climate conditions in August-September cause a moisture content in the root zone close to the permanent wilting point due to the decrease of the capillary rise, because the groundwater dropped deeper than 1.50 m-surface. Rainfall started to decrease at the beginning of July and the maximum decrease occurred in the period August-October (Figure 5).

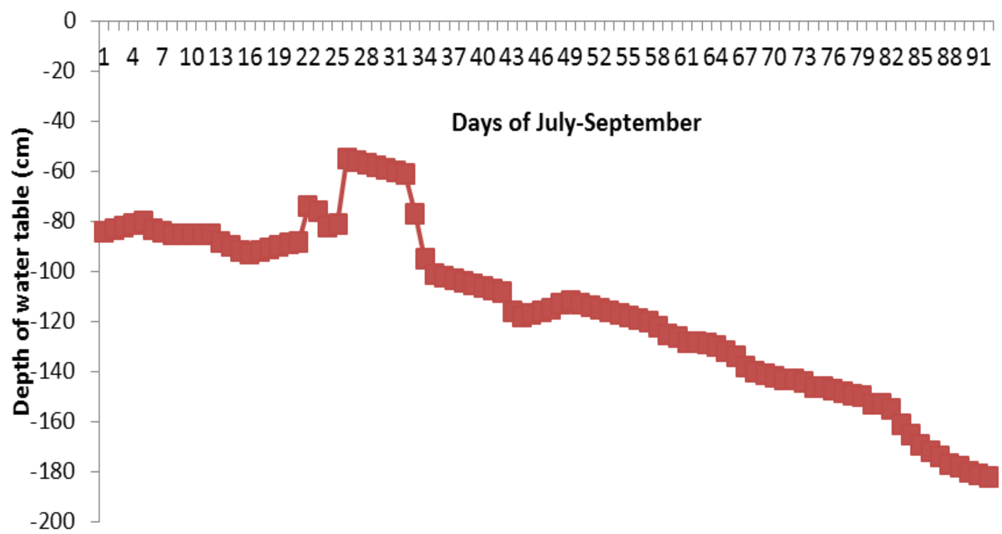


Figure 5. Groundwater level during the dry season of 2015 in Class B land

Cropping intensity on tidal lowland reclamation areas can be done two or even three times as an impact of land and water management. Farmers can grow rice-rice-corn in a year. In addition, intensive farming can decrease forest and land fire indirectly if the land is properly managed and utilized (Imanudin and Susanto, 2015).

Experiment of watermelon planting under shallow groundwater table conditions

The basic objective of the experiment was to analyse the possibilities for earlier planting of watermelon during the wet season in March or early April. For that reason the experiment was done in a greenhouse to identify the crop response to shallow groundwater table conditions.

Crop testing results for two groundwater conditions mentioned above showed that the crop can still grow at groundwater depth of 5 cm-surface with under optimal growth level. Watermelon had already growth at the 4th day for groundwater depth of 10 cm-surface, but it did not grow yet for the groundwater depth of 5 cm-surface. Plant height was 5.6 cm and the leaves were still bud (closed) with uplifted seed skin at the 6th day for the groundwater depth of 10 cm-surface, but prospective stem was just emerging for groundwater depth of 10 cm-surface. Plant height was 12.1 cm with 3 leaves at the 17th day for groundwater depth of 10 cm-surface, whereas it was 8.2 cm with 3 leaves at the 17th day for groundwater depth of 5 cm-surface. Average growth rate of the crop until the 17th day for groundwater depth of 10 cm-surface was 0.71 cm/day and its value was 0.48 cm/day for groundwater depth of 5 cm-surface. Crop growth description can be seen in Figure 6.

-5 cm -10 cm -15 cm

Figure 6. Visualization of watermelon response to shallow groundwater table conditions (15th day).

The laboratory experiment was stopped 20 days of after planting because it was estimated that the groundwater had dropped more than 20 cm-surface at field conditions. This period was at the end of the wet season (April) when farmers did planting at the end of March. The plant can be more adaptive to environment conditions during this period. Observations at the 20th day were conducted on watermelon treated with a groundwater table at 15 cm-surface. Plant height was 15.2 cm and it had 4 leaves. The plants had more leaves at this treatment than that the plants of the 10 and 5 cm-surface treatments.

Average plant height was 0.76 cm for the 15 cm-surface treatment. This value was relatively similar to the result obtained from 10 cm-surface. Therefore, watermelon cultivation can be started if field conditions show a groundwater level of 10 cm-surface. The contrast condition was found with the 5 cm-surface treatment, which showed stopping of the growth of root elongation. The root length was only 3.1 cm at 20 days after planting, which indicated that root growth avoids a high groundwater table.

Potential time of planting at Class C land

Results from greenhouse experiments also showed that watermelon can be planted under conditions of a shallow groundwater table between 10 and 15 cm-surface, if watermelon is cultivated at Class C land. The water in the tertiary canals can maintain the groundwater table. In tidal lowland areas, then the planting time can be accelerated to the end of February or planting can be directly conducted after rice harvesting. Planting can be done by using the hole system in which after clearance of rice straw a micro canal is being dug at every 6 to 8 m, using single plough equipment. The planting needs to be done quickly in order to prevent dryness. If planting is done at the end of February or in early March harvesting can be expected by the end of May. The generative phase would be in May. Observation results of the groundwater level fluctuation showed that planting could be done early March when the groundwater level was 20 to 30 cm-surface (Land and Water Management Tidal Lowlands (LWMTL), 2006). Dependent on the groundwater level planting could be done in February, but it is better to do it early March, because in February farmers are busy with first season rice harvesting. Water retention in canals needs to be provided in order to maintain a groundwater table close to the root zone.

The flowering phase in May poses a high risk, because the groundwater table frequently drops to 0.90 - 1.00 m-surface (Figure 7). Therefore, irrigation would be needed in this phase for at least two times application. Irrigation by pumps would be helpful to pump water from tertiary canals using furrow irrigation. High soil porosity in Class C land may cause that capillary water is not sufficiently available to fulfil the evapotranspiration requirement if the depth of the groundwater table is lower than 1.00 m-surface. This showed that the critical level of the groundwater table is at 1.00 m-surface for Class C land, whereas the critical level of the groundwater table is at 1.50 m-surface for Class B land, when dominated by clay soil. Analysis results of groundwater table fluctuation showed that watermelon cultivation can be done without irrigation in Class B land (Figure 8).

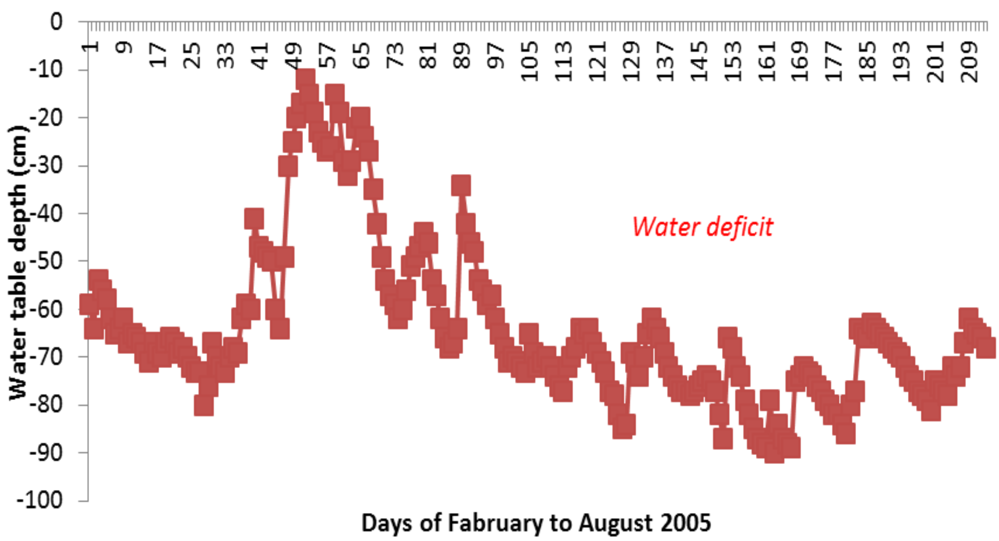


Figure 7. Groundwater table fluctuation at Class C tidal lowland area (LWMTL, 2006)

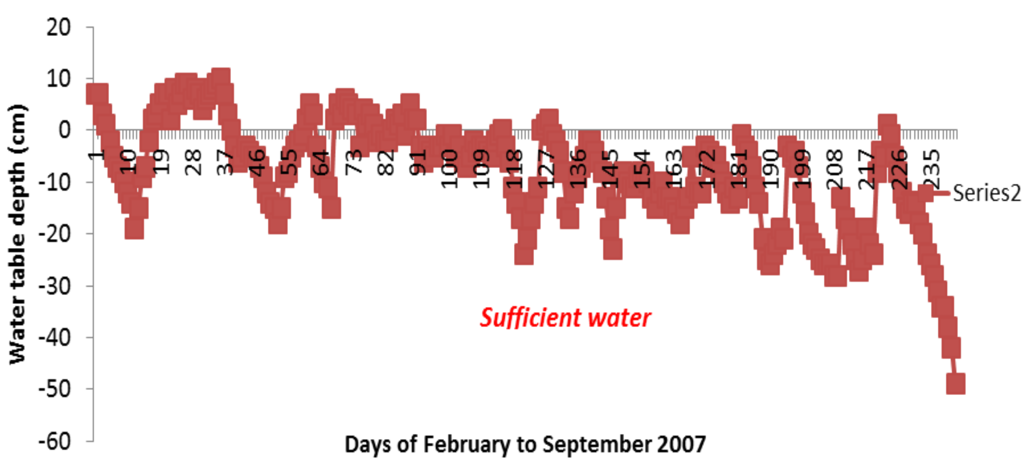


Figure 8. Groundwater fluctuation at Class B land (Imanudin *et al.*, 2010)

CONCLUSIONS

The following conclusions can be drawn from this study:

- Watermelon has the potential to be developed in tidal lowland areas because it is relatively tolerant to shallow groundwater depth in the initial growth phase. The crop was capable to grow at a groundwater depth of 5 cm-surface. Optimum growth was achieved at a groundwater depth of 15 cm-surface. However, field application showed that watermelon can be planted at a groundwater depth of 10 cm-surface. Results of the field study showed that a groundwater depth for Class B-C land had reached 15 cm-surface in March-April. Accelerated planting at the end of March is important in order to prevent dryness during the generative phase, when irrigation by gravity cannot be applied;
- crop adaptation to the groundwater table is depending on the planting time and land category. The crop could be planted in June and was harvested in September without irrigation in Class A and B lands. Capillary water at these land classes was sufficient to fulfil the evapotranspiration requirement. However, an earlier planting time in March and harvesting in May-June needs to be conducted at the Class C land, because this land had a high soil porosity. Capillary water during the dry season in this soil could not fulfil the evapotranspiration requirement. In June-September the groundwater could reach more than 1.20 m-surface;
- the tertiary canal needs to be equipped with a stop log, or flap gate to control the preferred groundwater table. The main option for Class A and B land was drainage, whereas for Class C land it was water retention.

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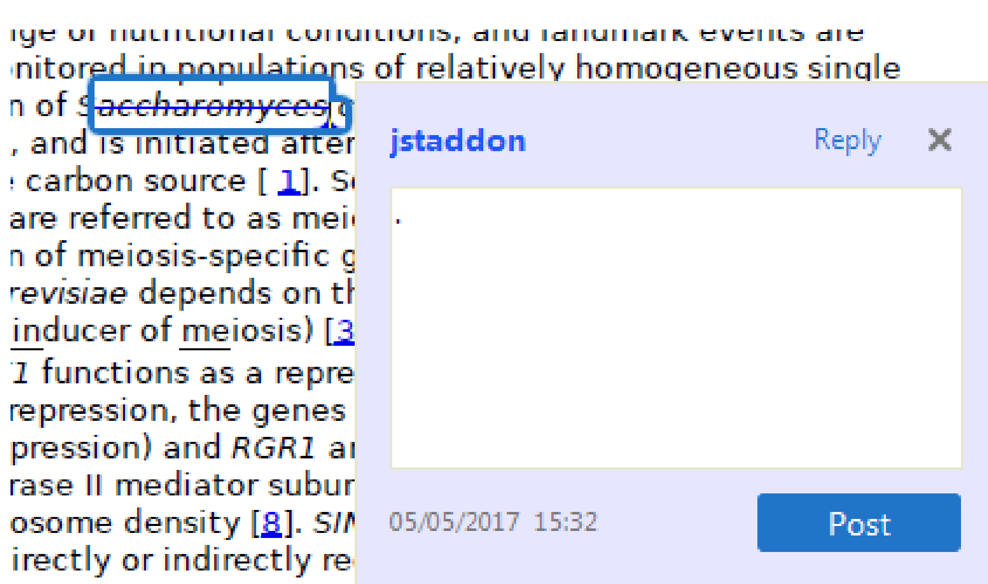

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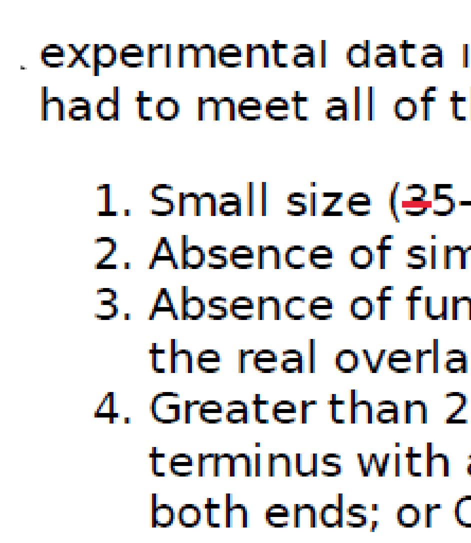

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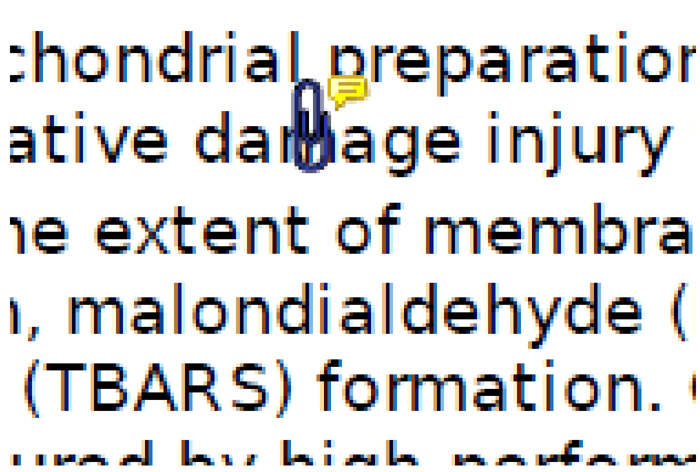

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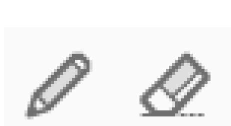

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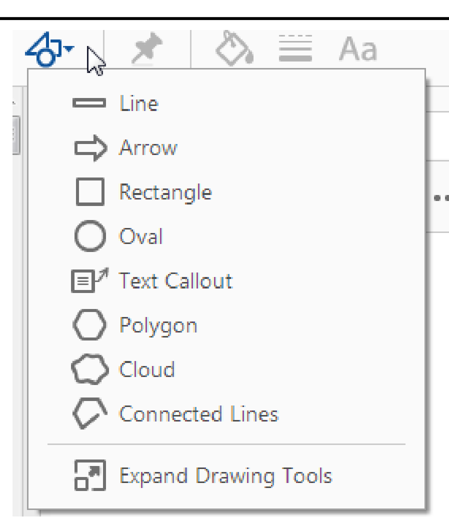

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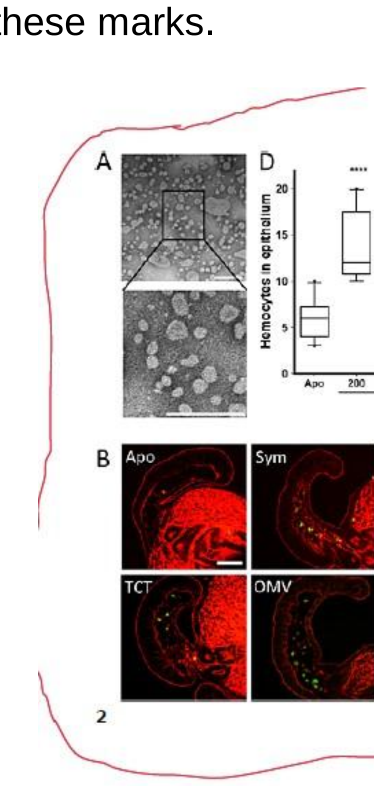

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, INDONESIA†

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ABSTRACT

Watermelon cultivation is one of the appropriate alternatives in order to increase farmers' income from tidal lowland agriculture. Research into crop adaptation to wet soil conditions is required to enable farmers to decide the best planting time under various conditions within the existing land classification. The research to determine crop physiological response during the initial growth period was conducted in a greenhouse. This was combined with field treatments based on groundwater table depths at 15, 10 and 5 cm-surface, respectively. Analysis of crop potential based on the water status conditions in the root zone was conducted by using secondary and primary data (daily records). Results of crop adaptation at shallow groundwater table depth showed that the treatments with groundwater table depth of 10 and 5 cm-surface were not significantly different in terms of plant height, with a size of 12.6 and 12.3 cm, having three leaves. However, it had a significant effect on root length, with a length of 11.9 and 3.1 cm, respectively. Maximum plant height of 15.2 cm and four leaves were found for the treatment with a groundwater table depth of 15 cm-surface. It may be concluded that it is best for farmers to plant at a groundwater table depth of 10 cm-surface. © 2019 John Wiley & Sons, Ltd.

key words: tidal lowland; watermelon; groundwater table; drainage

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RÉSUMÉ

La culture de la pastèque est l'une des alternatives appropriées pour augmenter les revenus des agriculteurs issus de l'agriculture des plaines de marée. Des recherches sur l'adaptation des cultures aux conditions de sol humides sont nécessaires pour permettre aux agriculteurs de décider du meilleur moment de plantation dans diverses conditions dans la classification des terres existante. Les recherches visant à déterminer la réponse physiologique des cultures au cours de la période de croissance initiale ont été menées en serre. Ceci a été combiné avec des traitements sur le terrain basés sur la profondeur de la nappe phréatique à 15, 10 et 5 cm de surface respectivement. L'analyse du potentiel des cultures en fonction des conditions de l'état de l'eau dans la zone racinaire a été réalisée à l'aide de données secondaires et primaires (enregistrements quotidiens). Les résultats de l'adaptation des cultures à la profondeur de la nappe phréatique peu profonde ont montré que les traitements avec une profondeur de la nappe phréatique de 10 et 5 cm n'étaient pas significativement différents en termes de hauteur de plants de 12,6 et 12,3 cm, avec trois feuilles. Cependant, il a eu un effet significatif sur la longueur de la racine avec une magnitude de 11,9 et 3,1 cm, respectivement. Une hauteur de plant maximale de 15,2 cm et quatre feuilles a été trouvée pour le traitement avec une profondeur de nappe phréatique de 15 cm. On peut en conclure que les agriculteurs peuvent mieux planter à une profondeur de la nappe phréatique de 10 cm. © 2019 John Wiley & Sons, Ltd.

mots clés: plaine de marée; pastèque; nappe phréatique; drainage

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†Détermination de la date de plantation de pastèques en agriculture sous nappe phréatique peu profonde des plaines de marées.

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INTRODUCTION

Tidal lowlands are low-lying, flat coastal plains, with a micro relief of not more than 1.00 m (Schultz *et al.*, 2013). Depending on the relative position of the land to the tide, the following classification has been made by the Directorate of Swamps (1984). There are four hydro-topographic classes:

- Class A is land below low high tide. The land can always receive water from the tide during the dry and wet seasons;
- Class B is land below high tide, but above land in Class A. The land can only receive tide water during the wet season;
- Class C is land not higher than 0.50 m above the highest tide. The water table is lower than 0.50 m-surface. Water supply from high tidal water cannot be provided because it is below the surface. Class C land is therefore highly dependent on rainfall;
- Class D is land above class C (upland soils). The land never receives water from the tide and is suitable for upland crops or plantations. The water table is deeper than 0.50 m-surface.

In tidal lowland areas tertiary canals have the function of collecting and discharging excess water during the wet season and if possible to supply fresh water during the dry season. When stop logs or flap gates are installed in these canals improved water management with a focus on these functions can be established (Suprianto *et al.*, 2010; Imanudin *et al.*, 2016).

Agriculture in tidal lowland areas of Indonesia has faced the problem of land use conversion from food crops to plantation crops. One way to control land use conversion in tidal lowland agriculture is to increase planting intensity. Studies by Imanudin *et al*. (2010, 2011) in tidal lowland in the Telang II area showed that the land had great potential for two or even three crops per year (Schultz *et al.*, 2015). The change of planting pattern from one into two times of planting can bring an equal income compared to that from oil palm. The change of planting pattern from *rice–fallow* into *rice–corn* and *rice–corn–corn* was more profitable (Imanudin and Bakri, 2014). Crop diversification with watermelon provides new prospects for farmers because it can result in a higher income compared to that of an oil palm plantation. The profit gained from watermelon cultivation with duration of 70–90 days can be as high as 30 million Rp/ha.[1] According to Gunawan (2014), if watermelon production is 11 t and the price is 3000 Rp kg^{-1}, then the net profit received by the farmers is about 18.5 million Rp.

Watermelon cultivation is therefore one of the appropriate alternatives in order to increase farmers' income from tidal lowland agriculture. However, information about the minimum depth of the groundwater table for crop planting is very important for farmers to determine the planting date. Therefore, research on crop adaptation to wet soil conditions is required to enable farmers to decide on the best planting time under various conditions within the existing land classification. This paper describes the experimental research on watermelon under greenhouse control conditions and validated by using groundwater data that have been recorded in the Telang area, South Sumatra.

BACKGROUND

The value of the benefit/cost (B/C) ratio is highly dependent on the cost of agricultural inputs. Research in Iran showed that there the B/C ratio of watermelon plants was 2.6 (Namdari, 2011). Adeboye *et al*. (2011) reported that the B/C ratios in Nigeria are lower at only 2.3 because of the costs of transportation and fertilizer. At present the larg- est watermelon-producing country is China. However, Indonesia is among the top 20 countries exporting the fruit (World atlas. 2019). A watermelon cultivation effort in the low- lands is considered to be useful as an option for farm enter- prize diversification.

Wang *et al*. (2017) reported that higher seasonal reference evapotranspiration (ETo) of watermelon resulted in higher fruit yield. Irrigation is needed for crop cultivation if rainfall during the growing season is less than 120 mm. They stated that 68 mm irrigation water will increase production by 46%. They also stated that irrigation water coupled with mulch can increase production by 11.4 t ha^{-1} compared to cultivation without mulch.

Evapotranspiration is strongly influenced by changes in groundwater depth. The closer the groundwater is to the soil surface, the higher the evapotranspiration. In lowland areas plant growth is highly dependent on water supply from capillary water movement. Results of a study by Singh *et al*. (2006) on *Typic Haplustalf* soil with a clay content of 45% showed capillary water movement of 18.7 mm day^{-1} at a groundwater depth of 0.90 m-surface. The groundwater contribution decreased to 10.7 mm day^{-1} at a groundwater depth of 1.20 m-surface. Results of a study by Singh *et al*. (2006) showed that groundwater contribution was 10.7 mm day^{-1} if the groundwater table depth was 1.20 m-surface for dominated clay textural soil. On the other hand, capillary water contribution was 4.8 mm day^{-1} if the groundwater table was at 0.74 m-surface and 2.5 mm/day if it was at 1.00 m-surface for sandy loam soil (Udom *et al*., 2013). The groundwater contribution in sandy clay soil at a groundwater depth of 0.74 m-surface was 4.76 mm day^{-1} and 2.45 mm day^{-1} at a groundwater depth of 1.00 m-surface (Udom *et al*., 2013). These data showed that groundwater movement at 1.00–1.20 m-surface is sufficient to fulfil the evapotranspiration requirement. However, the crop will require additional irrigation water if the groundwater is located deeper than 2.00 m-surface. Therefore, the water retention function to keep the groundwater table at 1.00–1.30 m-surface is very important if farmers cultivate crops during the dry season. Karimova *et al*. (2014) reported for the case of loamy clay soil that a groundwater table at 1.50 m-surface resulted in evapotranspiration of 47% and at 3 m-surface only of 23%. This finding showed that the crop required irrigation for maximum evapotranspiration at those positions. As reported by Pelletier *et al*. (2015), at a groundwater depth of 0.60 m-surface almost 70–80% irrigation water can be saved. According to Agele *et al*. (2015), variation in the contribution of capillary water to groundwater storage is a function of the groundwater depth. A high capillary rise is obtained when the depth of the groundwater table is within the threshold of the capillary rise during the harvesting period and evapotranspiration can be entirely sourced from groundwater. The simulations conducted by Gao *et al*. (2017) suggest that at a groundwater depth of 1.00 m-surface 40% of the evapotranspiration from plants is supplied from capillary water. Reported by Saraiva et al., (2018) to reduce water requirements in watermelon cultivation, mulch technology was successfully applied. Through that technology the production of watermelon reaches 73.66 Mg ha-1 with an irrigation water level of 314 mm.

The ideal conditions for crop growth are an available water condition between field capacity and permanent wilting point. Crop growth at the initial phase will be disturbed if the soil moisture is at 75% of exhausted available water, whereas optimum crop growth is at 50% of exhausted avail-

Q10 able water (Modi and Zulu, 2012). A crop which is flooded during a short time will experience hypoxia (lack of O_2). Hypoxia usually occurs if parts of the crop roots are flooded (the crown part is not flooded) or when the crop is flooded for a long time but crop roots are located near the soil surface. If all parts of a crop are flooded, then the roots are located deeper in the soil and experience flooding for a longer time so that the crop is in anoxia condition (an environment without O_2). The anoxia condition occurs 6–8 h after flooding because O_2 is suppressed by water and the rest of the O_2 is utilized by microorganisms. The left-over O_2 content within the soil during flooded conditions with a crop is used up faster because the O_2 diffusion rate within a wet soil is 10 000 times slower than that in air (Amstrong, 1979). Conditions of hypoxia or anoxia not only prevent N fixation, but also distribution of N and other minerals, which in turn impede root growth and nodulation. Leaves will experience yellowing followed by leaf fall due to insufficient transportation of N and minerals into the crown part. Scott and Fisher (1989) reported that flooding effects were indicated by leaf yellowing, leaf fall at the lowest joint, dwarf and a Q11 decrease of dry matter weight and crop yield. According to Hapsari and Adie (2010), results of their study on soybeans showed that yield losses at the vegetative phase were generally lower than during the reproductive phase, having values of 17–43 and 50–56% respectively. The magnitude of yield losses was dependent on crop variety, crop growth phase, flooding period, soil texture and the existence of crop weeds and diseases. According to Pasaribu *et al*. (2013), under tropical climatic conditions in *ultisol* soil the crop water requirement for watermelon is 2.8 mm day^{-1} for the initial growth phase, 6.2 mm day^{-1} for the middle growth phase and 4.4 mm day^{-1} for the final growth phase, respectively.

Tidal lowland areas with a shallow groundwater table have a high potential for watermelon cultivation. The groundwater contribution through capillary flow is sufficient to provide the crop water requirement (Imanudin and Bakri, 2014). This condition has the advantage that irrigation is not needed, resulting in cost saving. Imanudin *et al*. (2010) Q12 stated that controlled drainage is the best option to maintain preferred water levels in lowland areas. Farmers would have to install hydraulic structures in tertiary canals in order to control the open water table at levels in such a way that optimal growth conditions for the crops are created. However, if planting is delayed at flowering stage during the dry season and the groundwater depth exceeds 1.50 m-surface, irrigation by pumping needs to be provided (Singh *et al.*, 2006). In addition, a long period of flooding results in abiotic stress of the crop, which affects the sprout growth rate, seed development and subsequently affects crop growth and development, especially during the initial growth period (Dat *et al.*, 2000). The food crop is capable of tolerating a water content level which exceeds the field capacity by 25% (Prawoto *et al.*, 2005).

In the Telang area during the November–January period the water is generally above the soil surface with a 10–20 cm inundation height. In this period rice is planted (first season), entering at February the water level is Q13 gradually lowered to a depth of 20–30 cm-surface and the rice reaches the harvest period (Imanudin and Bakri, 2014). According to Bakri *et al*. (2014) the groundwater Q14 levels after rice harvesting are still high enough for the cultivation of a second crop. If there are tertiary gates then they will be operated to achieve maximum drainage. In the March–April period, groundwater levels in tidal lowlands that have a Class B hydro-topography are in the range of 20–30 cm-surface. Thus the soil moisture in the root zone is still too wet for a second crop like corn. However watermelon plants could be planted by the end of April.

Based on the above discussion, applied research was considered to be required to determine watermelon crop response at the initial phase to shallow groundwater table conditions.

Figure 2. Experimental application of groundwater depth to supply irrigation water to the crop [Colour figure can be viewed at wileyonlinelibrary.com]

MATERIALS AND METHODS

The research was conducted from March to April 2016 in the greenhouse at the Agroecotechnology Department, Faculty of Agriculture, Sriwijaya University. Data of daily groundwater level from secondary data and direct observations were used to analyse the planting time. The secondary data were obtained in tidal lowland pilot project areas in the Telang I area. The direct observations were done on a tertiary plot in the Telang II area in 2015 (Imanudin *et al.*, 2010).

Materials and equipment used in this study were soil, having a sandy loam texture, watermelon seeds, water and aqua bottles. Equipment for groundwater level control was obtained by using the continuous flow system (Figure 1) in which the groundwater level is kept in equilibrium with that in a reservoir using the principle of connected vessels. The experimental application of groundwater depth to supply irrigation by capillary rise is presented in Figure 2.
Treatments consisted of maintaining groundwater depth at 5, 10 and 15 cm-surface. In order to maintain a constant groundwater level, the water height in the column was kept constant, which required daily observation. Crop growth was determined by measuring height as well as number of leaves at 2 weeks after planting. Root length and number of leaves for each treatment were also observed at the end of the experiment.

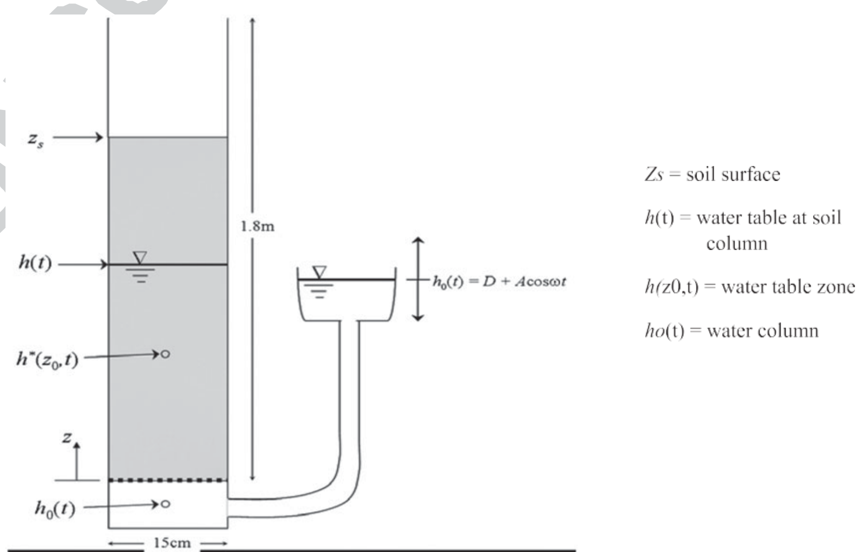
F1 F2

To determine the best planting in the field, daily groundwater data were analysed by comparing the greenhouse experimental result of watermelon growth response to shallow groundwater tables in the initial phase. Data analysis of the daily groundwater level was carried out to determine planting potential in the field. The data of daily groundwater level were also compared with rainfall data in 2015 that were obtained from Kenten Climatologic Station in Palembang.

RESULTS AND DISCUSSION

Study of planting potential in tidal lowland area

Watermelon cultivation in tidal lowland areas is highly dependent on the season. Planting in the wet season cannot be implemented due to the very high groundwater level as a



Q15 Figure 1. Experimental set-up of groundwater contribution to crop water requirement (Udom *et al*., 2013)

F3 result of rainfall. Figure 3 shows groundwater level observations in the Telang I area in 2009, which indicate that the groundwater was too saturated up to May for cultivation of crops, except for rice. Planting could be done by the end of May or early June with as a consequence that the crops frequently experienced dryness during the generative phase in August.

When structures in the tertiary canals have been installed, then according to Bakri *et al*. (2015) the water management objective for crop cultivation in the period June–September will be water retention within the tertiary canals. If high fresh tidal water can still enter the tertiary canal, then a proper water gate is a stop log with a retention level of 0.50 m from the bottom level of the canal. The stop log height would have to be regulated such that high tidal water can enter the canal and water is held at a minimum of 0.50 m-surface during the low tide period. If an automatic fibre flap gate has been installed, then the gate position during the dry season needs to be before the culvert at the downstream side of the tertiary canal so that high tidal water can enter the canal and the gate will automatically close during the low tide period. However, such gates can easily be damaged and cannot be repaired by the farmers (Imanudin *et al.,* 2016).

Although in November high tidal water can be blocked to prevent it from getting on to the land, high rainfall intensity coupled with insufficient duration of low tide for discharge will result in full canals and it will be difficult to F4 achieve groundwater drawdown. Figure 4 shows data of groundwater-level fluctuation from February to March on Class B land in 2015. The drastic upward movement of the groundwater level was due to rainfall. At that time there were no structures and the tide water could enter the tertiary block, so the land had more excess water and a higher groundwater level or inundation during the wet season. The groundwater level dropped continuously in the case of no rainfall. In addition to the structures in the tertiary canals, in the concerned area a micro water management system

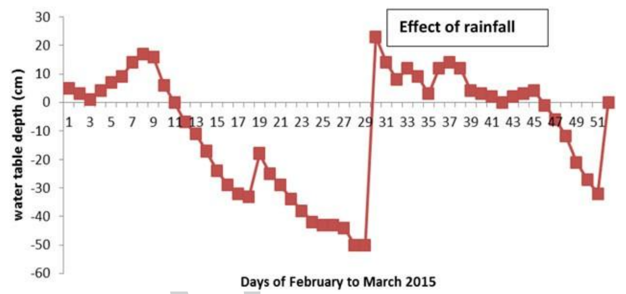


Figure 4. Groundwater level in February and March 2015 under dry conditions [Colour figure can be viewed at wileyonlinelibrary.com]

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was installed. The system consists of small canals (called *micro channels*) at 8 m spacing, having a depth of 20 cm. The data in Figure 9 show that the micro water management system was relatively effective in lowering the groundwater level. However, farmers could not do planting in early March because the average depth of the groundwater level was less than 10 cm-surface. Figure 3 also shows that there was flooding for 10–12 days. Direct planting of watermelon seeds could not be done in these conditions and could only be done on the 14th day or in the middle of March. Q16

Planting would have to be done at the end of the wet season in April or as a result of the El Nino effect in 2015 even in March due to the dry conditions. Crop adaptation to dry conditions could start planting in the early growth period in the wet season. The decision to move the planting time forward was made to prevent water deficiency during the generative growth phase. Dry climate conditions in August–September cause moisture content in the root zone to be close to the permanent wilting point due to the decrease of the capillary rise, because the groundwater dropped deeper than 1.50 m-surface. Rainfall started to decrease at the beginning of July and the maximum decrease occurred in the period August–October (Figure 5). F5

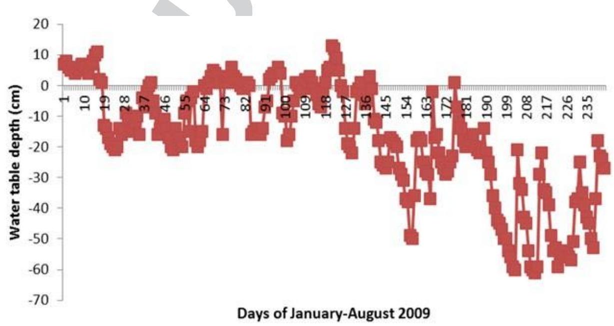

Figure 3. Groundwater level during the January–August period in normal conditions (Imanudin *et al.*, 2010) [Colour figure can be viewed at wileyonlinelibrary.com]

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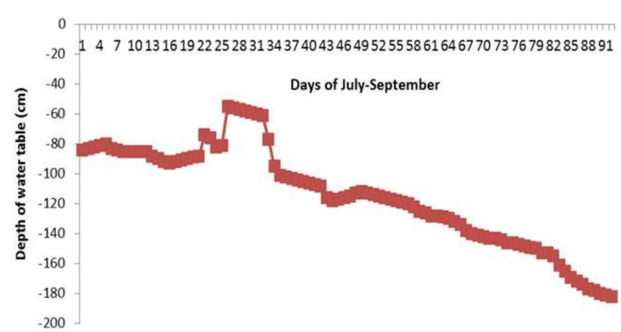

Figure 5. Groundwater level during the dry season of 2015 on Class B land [Colour figure can be viewed at wileyonlinelibrary.com]

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Planting intensity can be done two or even three times as an impact of land and water management. In addition, intensive farming can decrease forest and land fires indirectly if the land is properly managed and utilized (Imanudin and Susanto, 2015).

Experiment of watermelon planting under shallow groundwater table conditions

The basic objective of the experiment was to analyse the possibilities for earlier planting of watermelon during the wet season in March or early April. For that reason the experiment was carried out in a greenhouse to identify the crop response to shallow groundwater table conditions.

Crop testing results for two groundwater conditions mentioned above showed that the crop can still grow at a groundwater depth of 5 cm-surface with a less than optimal growth level. Watermelon had already grown on the fourth day with a groundwater depth of 10 cm-surface, but it had not grown with a groundwater depth of 5 cm-surface. Plant height was 5.6 cm and the leaves were still cringe (closed) with uplifted seed skin on the sixth day with a groundwater depth of 10 cm-surface, but stem prospective was just emerging for a groundwater depth of 10 cm-surface. Plant height was 12.1 cm with three leaves on the 17th day with a groundwater depth of 10 cm-surface, whereas it was 8.2 cm with three leaves on the 17th day with a groundwater depth of 5 cm-surface. Average growth rate of the crop until the 17th day for a groundwater depth of 10 cm-surface was 0.71 cm day^{-1} and its value was 0.48 cm day^{-1} for a groundwater depth of 5 cm-surface. A crop growth description is given in Figure 6.

The laboratory experiment was stopped 20 days after planting because it was estimated that the groundwater had dropped more than 20 cm-surface in field conditions. This period was at the end of the wet season (April) when farmers did their planting at the end of March. The plants can be more adaptive to environment conditions during this period. Observations on the 20th day were conducted on watermelon treated with a groundwater table at 15 cm-surface. Plant height was 15.2 cm and it had four leaves. The plants had more leaves with this treatment than those of the 10 and 5 cm-surface treatments.

Average plant height was 0.76 cm for the 15 cm-surface treatment. This value was relatively similar to the result obtained from that of 10 cm-surface. Therefore, watermelon cultivation can be started if field conditions show a groundwater level of 10 cm-surface. A contrasting condition was found with the 5 cm-surface treatment, which showed a cessation of the growth of root elongation. The root length was only 3.1 cm at 20 days after planting, which indicated that root growth avoids a high groundwater table.

Potential time of planting on Class C land

The results from greenhouse experiments also showed that watermelon can be planted under conditions of a shallow groundwater table between 10 and 15 cm-surface, if watermelon is cultivated on Class C land. The water in the tertiary canals can maintain the groundwater table. In tidal lowland areas, then, the planting time can be accelerated to the end of February or planting can be directly conducted after rice harvesting. Planting can be done by using the hole system in which after clearance of rice straw a micro canal is dug every 6–8 m, using a single plough. The planting needs to be done quickly in order to prevent drying out. If planting is done at the end of February or in early March harvesting can be expected by the end of May. The generative phase would be in May. Observation results of the groundwater-level fluctuation showed that planting could be done in early March when the groundwater level was 20–30 cm-surface (Land and Water Management Tidal Lowlands (LWMTL), 2006). Depending on the groundwater level, planting could be done in February, but it is better to do it in early March,

Colour online, B&W in print

Figure 6. Visualization of watermelon response to shallow groundwater table conditions (15th day) [Colour figure can be viewed at wileyonlinelibrary.com]

Colour online, B&W in print

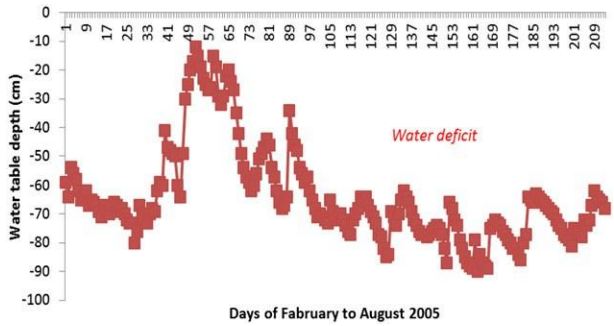

Figure 7. Groundwater table fluctuation in a Class C tidal lowland area (LWMTL, 2006) [Colour figure can be viewed at wileyonlinelibrary.com]

Colour online, B&W in print

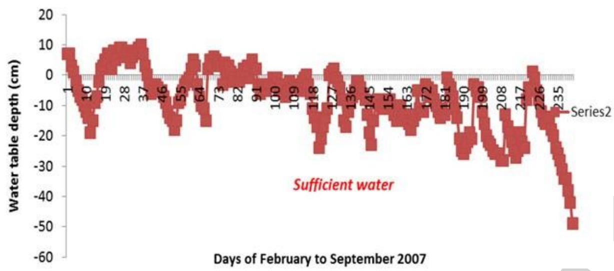

Figure 8. Groundwater fluctuation on Class B land (Imanudin *et al.,* 2010) [Colour figure can be viewed at wileyonlinelibrary.com]

because in February farmers are busy with first-season rice harvesting. Water retention in canals needs to be provided in order to maintain a groundwater table close to the root zone.

The flowering phase in May poses a high risk, because the groundwater table frequently drops to 0.90–1.00 m-surface (Figure 7). Therefore, irrigation would be needed in this phase and be applied twice. Irrigation by pumps would be helpful to pump water from tertiary canals using furrow irrigation. High soil porosity in Class C land may mean that capillary water is not sufficiently available to fulfil the evapotranspiration requirement if the depth of the groundwater table is lower than 1.00 m-surface. This showed that the critical level of the groundwater table is 1.00 m-surface for Class C land, whereas it is at 1.50 m-surface for Class B land, when dominated by clay soil. Analysis results of groundwater table fluctuation showed that watermelon cultivation can be carried on without irrigation on Class B land (Figure 8).

CONCLUSIONS

The following conclusions can be drawn from this study:

- Watermelon has the potential to be developed in tidal lowland areas because it is relatively tolerant to shallow groundwater depth in the initial growth phase. The crop was able to grow at a groundwater depth of 5 cm-surface. Optimum growth was achieved at a groundwater depth of 15 cm-surface. However, field application showed that watermelon can be planted at a groundwater depth of 10 cm-surface. Results of the field study showed that a groundwater depth for Class B–C land had reached 15 cm-surface in March–April. Accelerated planting at the end of March is important in order to prevent dryness during the generative phase, when irrigation by gravity cannot be applied;
- crop adaptation to the groundwater table is dependent on planting time and land category. The crop could be planted in June and be harvested in September without irrigation in Class A and B land. Capillary water on these land classes was sufficient to fulfil the evapotranspiration requirement. However, an earlier planting time in March and harvesting in May–June needs to be conducted on Class C land, because this land had a high soil porosity. Capillary water during the dry season in this soil could not fulfil the evapotranspiration requirement. In June–September the groundwater could reach more than 1.20 m-surface;
- the tertiary canal needs to be equipped with a stop log or flap gate to control the preferred groundwater table. The main option for Class A and B land was drainage, whereas for Class C land it was water retention.

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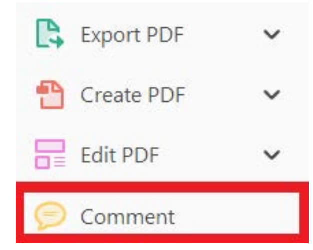

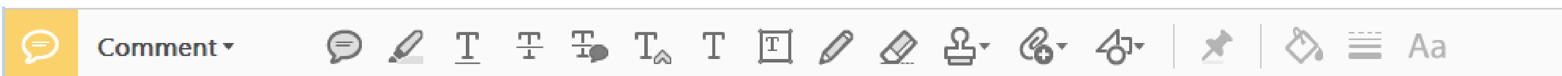

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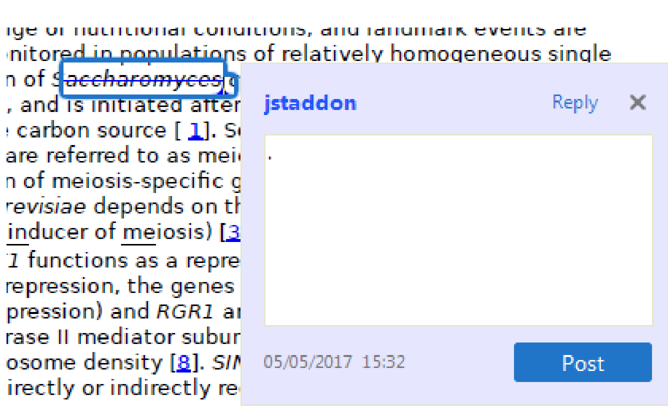

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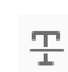

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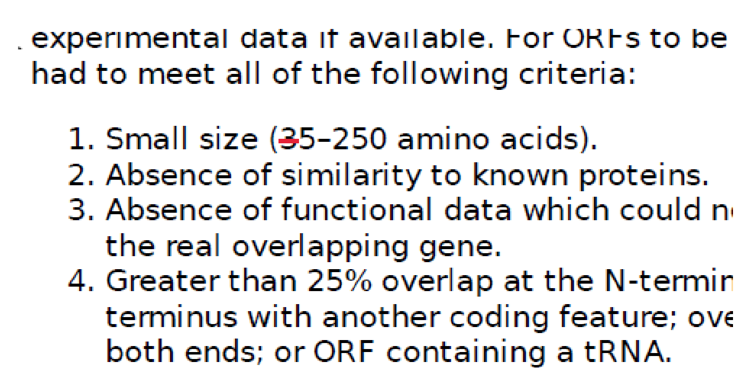

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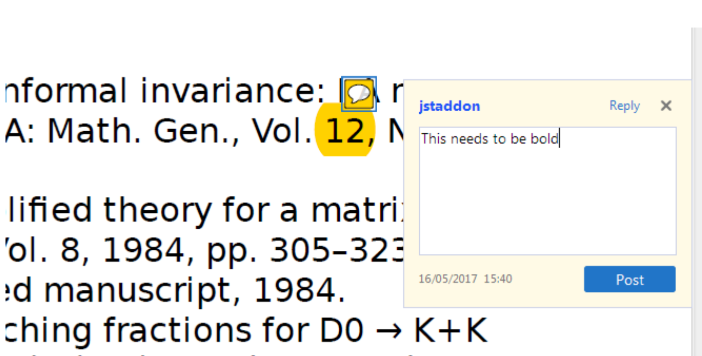

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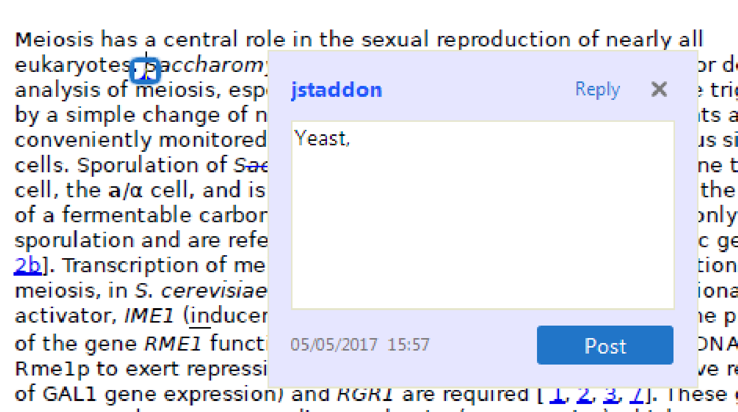

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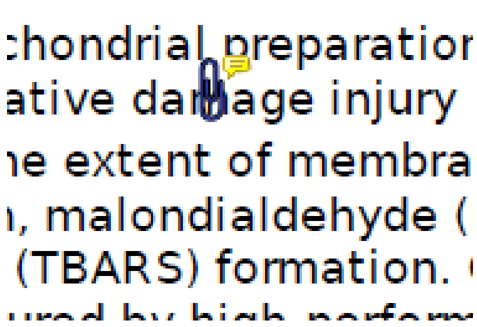

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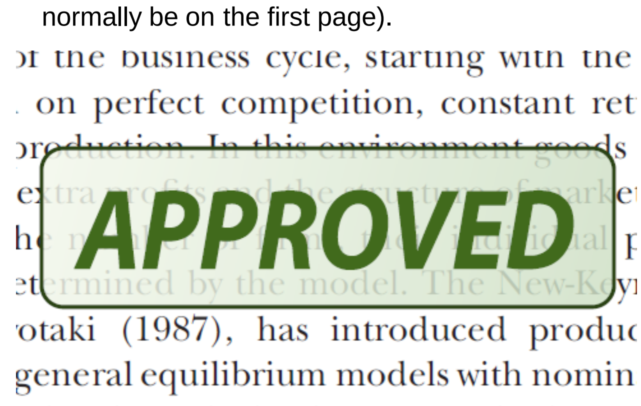

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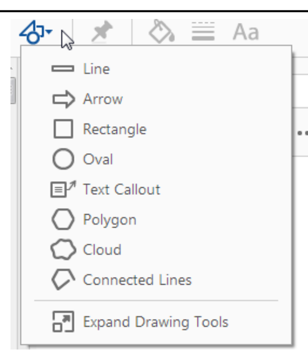

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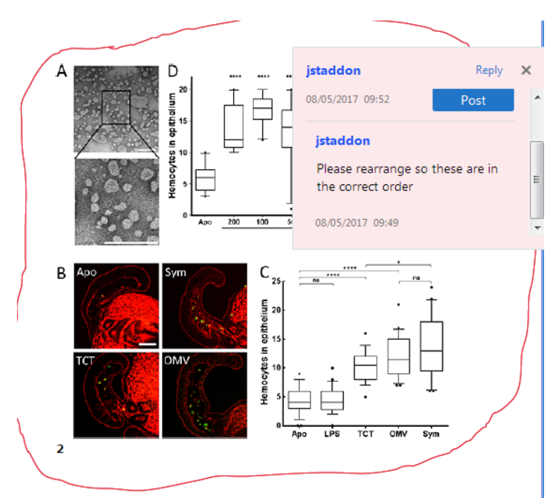

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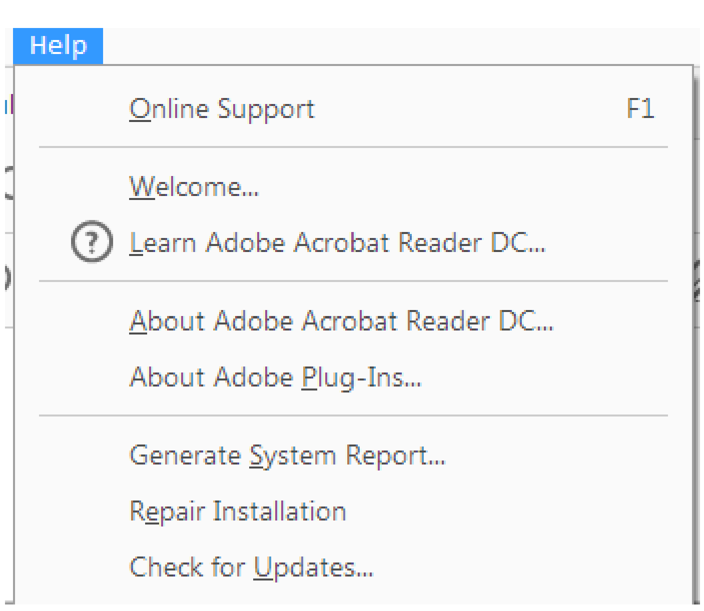

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DETERMINATION OF PLANTING TIME OF WATERMELON UNDER A SHALLOW GROUNDWATER TABLE IN TIDAL LOWLAND AGRICULTURE AREAS OF SOUTH SUMATRA, INDONESIA†

Q2 MOMON SODIK IMANUDIN*, M.E. ARMANTO AND BAKRI

Department of Soil Science, Faculty of Agriculture, Sriwijaya University, Palembang, Indonesia

ABSTRACT

Watermelon cultivation is one of the appropriate alternatives in order to increase farmers' income from tidal lowland agriculture. Research into crop adaptation to wet soil conditions is required to enable farmers to decide the best planting time under various conditions within the existing land classification. The research to determine crop physiological response during the initial growth period was conducted in a greenhouse. This was combined with field treatments based on groundwater table depths at 15, 10 and 5 cm-surface, respectively. Analysis of crop potential based on the water status conditions in the root zone was conducted by using secondary and primary data (daily records). Results of crop adaptation at shallow groundwater table depth showed that the treatments with groundwater table depth of 10 and 5 cm-surface were not significantly different in terms of plant height, with a size of 12.6 and 12.3 cm, having three leaves. However, it had a significant effect on root length, with a length of 11.9 and 3.1 cm, respectively. Maximum plant height of 15.2 cm and four leaves were found for the treatment with a groundwater table depth of 15 cm-surface. It may be concluded that it is best for farmers to plant at a groundwater table depth of 10 cm-surface. © 2019 John Wiley & Sons, Ltd.

KEY WORDS: tidal lowland; watermelon; groundwater table; drainage

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RÉSUMÉ

La culture de la pastèque est l'une des alternatives appropriées pour augmenter les revenus des agriculteurs issus de l'agriculture des plaines de marée. Des recherches sur l'adaptation des cultures aux conditions de sol humides sont nécessaires pour permettre aux agriculteurs de décider du meilleur moment de plantation dans diverses conditions dans la classification des terres existante. Les recherches visant à déterminer la réponse physiologique des cultures au cours de la période de croissance initiale ont été menées en serre. Ceci a été combiné avec des traitements sur le terrain basés sur la profondeur de la nappe phréatique à 15, 10 et 5 cm de surface respectivement. L'analyse du potentiel des cultures en fonction des conditions de l'état de l'eau dans la zone racinaire a été réalisée à l'aide de données secondaires et primaires (enregistrements quotidiens). Les résultats de l'adaptation des cultures à la profondeur de la nappe phréatique peu profonde ont montré que les traitements avec une profondeur de la nappe phréatique de 10 et 5 cm n'étaient pas significativement différents en termes de hauteur de plants de 12,6 et 12,3 cm, avec trois feuilles. Cependant, il a eu un effet significatif sur la longueur de la racine avec une magnitude de 11,9 et 3,1 cm, respectivement. Une hauteur de plant maximale de 15,2 cm et quatre feuilles a été trouvée pour le traitement avec une profondeur de nappe phréatique de 15 cm. On peut en conclure que les agriculteurs peuvent mieux planter à une profondeur de la nappe phréatique de 10 cm. © 2019 John Wiley & Sons, Ltd.

MOTS CLÉS: plaine de marée; pastèque; nappe phréatique; drainage

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†Détermination de la date de plantation de pastèques en agriculture sous nappe phréatique peu profonde des plaines de marées.

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INTRODUCTION

Tidal lowlands are low-lying, flat coastal plains, with a micro relief of not more than 1.00 m (Schultz *et al.,* 2013). Depending on the relative position of the land to the tide, the following classification has been made by the Directorate of Swamps (1984). There are four hydro-topographic classes:

- Class A is land below low high tide. The land can always receive water from the tide during the dry and wet seasons;
- Class B is land below high tide, but above land in Class A. The land can only receive tide water during the wet season;
- Class C is land not higher than 0.50 m above the highest tide. The water table is lower than 0.50 m-surface. Water supply from high tidal water cannot be provided because it is below the surface. Class C land is therefore highly dependent on rainfall;
- Class D is land above class C (upland soils). The land never receives water from the tide and is suitable for upland crops or plantations. The water table is deeper than 0.50 m-surface.

In tidal lowland areas tertiary canals have the function of collecting and discharging excess water during the wet season and if possible to supply fresh water during the dry season. When stop logs or flap gates are installed in these canals improved water management with a focus on these functions can be established (Suprianto *et al.,* 2010; Imanudin *et al.,* 2016).

Agriculture in tidal lowland areas of Indonesia has faced the problem of land use conversion from food crops to plantation crops. One way to control land use conversion in tidal lowland agriculture is to increase planting intensity. Studies by Imanudin *et al.* (2010, 2011) in tidal lowland in the Telang II area showed that the land had great potential for two or even three crops per year (Schultz *et al.,* 2015). The change of planting pattern from one into two times of planting can bring an equal income compared to that from oil palm. The change of planting pattern from *rice–fallow* into *rice–corn* and *rice–corn–corn* was more profitable (Imanudin and Bakri, 2014). Crop diversification with watermelon provides new prospects for farmers because it can result in a higher income compared to that of an oil palm plantation. The profit gained from watermelon cultivation with duration of 70–90 days can be as high as 30 million Rp/ha.[1] According to Gunawan (2014), if watermelon production is 11 t and the price is 3000 Rp kg^{-1}, then the net profit received by the farmers is about 18.5 million Rp.

Watermelon cultivation is therefore one of the appropriate alternatives in order to increase farmers' income from tidal lowland agriculture. However, information about the minimum depth of the groundwater table for crop planting is very important for farmers to determine the planting date. Therefore, research on crop adaptation to wet soil conditions is required to enable farmers to decide on the best planting time under various conditions within the existing land classification. This paper describes the experimental research on watermelon under greenhouse control conditions and validated by using groundwater data that have been recorded in the Telang area, South Sumatra.

BACKGROUND

The value of the benefit/cost (B/C) ratio is highly dependent on the cost of agricultural inputs. Research in Iran showed that there the B/C ratio of watermelon plants was 2.6 (Namdari, 2011). Adeboye *et al.* (2011) reported that the Q4 B/C ratios in Nigeria are lower at only 2.3 because of the costs of transportation and fertilizer. At present the largest watermelon-producing country is China. However, Indonesia is among the top 20 countries exporting the fruit (Food and Agriculture Organization of the United Nations Q5 (FAO), 2014) A watermelon cultivation effort in the lowlands is considered to be useful as an option for farm enterprise diversification.

Wang *et al.* (2004) reported that irrigation is needed for Q6 crop cultivation if rainfall during the growing season is less than 120 mm. They stated that 68 mm irrigation water will increase production by 46%. They also stated that irrigation water coupled with mulch can increase production by 11.4 t ha^{-1} compared to cultivation without mulch.

Evapotranspiration is strongly influenced by changes in groundwater depth. The closer the groundwater is to the soil surface, the higher the evapotranspiration. In lowland areas plant growth is highly dependent on water supply from capillary water movement. Results of a study by Singh *et al.* (2006) on *Typic Haplustalf* soil with a clay content of 45% showed capillary water movement of 18.7 mm day^{-1} at a groundwater depth of 0.90 m-surface. The groundwater contribution decreased to 10.7 mm day^{-1} at a groundwater depth of 1.20 m-surface. Results of a study by Singh *et al.* (2006) showed that groundwater contribution was 10.7 mm day^{-1} if the groundwater table depth was 1.20 m-surface for dominated clay textural soil. On the other hand, capillary water contribution was 4.8 mm day^{-1} if the groundwater table was at 0.74 m-surface and 2.5 mm/day if it was at 1.00 m-surface for sandy loam soil (Udom *et al.*, Q7 2013). The groundwater contribution in sandy clay soil at a groundwater depth of 0.74 m-surface was 4.76 mm day^{-1} and 2.45 mm day^{-1} at a groundwater depth of 1.00 m-surface (Udom *et al.*, 2013). These data showed that groundwater movement at 1.00–1.20 m-surface is sufficient to fulfil the evapotranspiration requirement. However, the crop will require additional irrigation water if the groundwater is located deeper than 2.00 m-surface. Therefore, the water retention function to keep the groundwater table at 1.00–1.30 m-surface is very important if farmers cultivate crops during the dry season. Karimova *et al*. (2014) reported for the case of loamy clay soil that a groundwater table at 1.50 m-surface resulted in evapotranspiration of 47% and at 3 m-surface only of 23%. This finding showed that the crop required irrigation for maximum evapotranspiration at those positions. As reported by Pelletier *et al*. (2015), at a groundwater depth of 0.60 m-surface almost 70–80% irrigation water can be saved. According to Agele *et al*. (2015), variation in the contribution of capillary water to groundwater storage is a function of the groundwater depth. A high capillary rise is obtained when the depth of the groundwater table is within the threshold of the capillary rise during the harvesting period and evapotranspiration can be entirely sourced from groundwater. The simulations conducted by Gao *et al*. (2017) suggest that at a groundwater depth of 1.00 m-surface 40% of the evapotranspiration from plants is supplied from capillary water.

Humphries and Wheeler (1963) stated that the number of leaves and the size were affected by genotype and environment. Q8 The leaf position of a plant which is primarily controlled by genotype also has an effect on leaf growth rate, final size of leaves and better response capacity to the environment, such as water availability. A crop which is capable of producing higher photosynthesis will produce more leaves because photosynthesis will be used to develop crop organs, such as leaves and trunk, in accordance with the increase in crop dry matter weight Q9 (Hasanuddin, 1996).

The ideal conditions for crop growth are an available water condition between field capacity and permanent wilting point. Crop growth at the initial phase will be disturbed if the soil moisture is at 75% of exhausted available water, whereas optimum crop growth is at 50% of exhausted available Q10 water (Modi and Zulu, 2012). A crop which is flooded during a short time will experience hypoxia (lack of O_2). Hypoxia usually occurs if parts of the crop roots are flooded (the crown part is not flooded) or when the crop is flooded for a long time but crop roots are located near the soil surface. If all parts of a crop are flooded, then the roots are located deeper in the soil and experience flooding for a longer time so that the crop is in anoxia condition (an environment without O_2). The anoxia condition occurs 6–8 h after flooding because O_2 is suppressed by water and the rest of the O_2 is utilized by microorganisms. The left-over O_2 content within the soil during flooded conditions with a crop is used up faster because the O_2 diffusion rate within a wet soil is 10 000 times slower than that in air (Amstrong, 1979). Conditions of hypoxia or anoxia not only prevent N fixation, but also distribution of N and other minerals, which in turn impede root growth and nodulation. Leaves will experience yellowing followed by leaf fall due to insufficient transportation of N and minerals into the crown part. Scott and Fisher (1989) reported that flooding effects were indicated by leaf yellowing, leaf fall at the lowest joint, dwarf and a Q11 decrease of dry matter weight and crop yield. According to Hapsari and Adie (2010), results of their study on soybeans showed that yield losses at the vegetative phase were generally lower than during the reproductive phase, having values of 17–43 and 50–56% respectively. The magnitude of yield losses was dependent on crop variety, crop growth phase, flooding period, soil texture and the existence of crop weeds and diseases. According to Pasaribu *et al*. (2013), under tropical climatic conditions in *ultisol* soil the crop water requirement for watermelon is 2.8 mm day^{-1} for the initial growth phase, 6.2 mm day^{-1} for the middle growth phase and 4.4 mm day^{-1} for the final growth phase, respectively.

Tidal lowland areas with a shallow groundwater table have a high potential for watermelon cultivation. The groundwater contribution through capillary flow is sufficient to provide the crop water requirement (Imanudin and Bakri, 2014). This condition has the advantage that irrigation is not needed, resulting in cost saving. Imanudin *et al*. (2010) Q12 stated that controlled drainage is the best option to maintain preferred water levels in lowland areas. Farmers would have to install hydraulic structures in tertiary canals in order to control the open water table at levels in such a way that optimal growth conditions for the crops are created. However, if planting is delayed at flowering stage during the dry season and the groundwater depth exceeds 1.50 m-surface, irrigation by pumping needs to be provided (Singh *et al.,* 2006). In addition, a long period of flooding results in abiotic stress of the crop, which affects the sprout growth rate, seed development and subsequently affects crop growth and development, especially during the initial growth period (Dat *et al.,* 2000). The food crop is capable of tolerating a water content level which exceeds the field capacity by 25% (Prawoto *et al.,* 2005).

In the Telang area during the November–January period the water is generally above the soil surface with a 10–20 cm inundation height. In this period rice is planted (first season), entering at February the water level is Q13 gradually lowered to a depth of 20–30 cm-surface and the rice reaches the harvest period (Imanudin and Bakri, 2014). According to Bakri *et al*. (2014) the groundwater Q14 levels after rice harvesting are still high enough for the cultivation of a second crop. If there are tertiary gates then they will be operated to achieve maximum drainage. In the March–April period, groundwater levels in tidal lowlands that have a Class B hydro-topography are in the range of 20–30 cm-surface. Thus the soil moisture in the root zone is still too wet for a second crop like corn. However watermelon plants could be planted by the end of April.

Based on the above discussion, applied research was considered to be required to determine watermelon crop response at the initial phase to shallow groundwater table conditions.

MATERIALS AND METHODS

The research was conducted from March to April 2016 in the greenhouse at the Agroecotechnology Department, Faculty of Agriculture, Sriwijaya University. Data of daily groundwater level from secondary data and direct observations were used to analyse the planting time. The secondary data were obtained in tidal lowland pilot project areas in the Telang I area. The direct observations were done on a tertiary plot in the Telang II area in 2015 (Imanudin *et al.,* 2010).

Materials and equipment used in this study were soil, having a sandy loam texture, watermelon seeds, water and aqua bottles. Equipment for groundwater level control was obtained by using the continuous flow system (Figure 1) in which the groundwater level is kept in equilibrium with that in a reservoir using the principle of connected vessels. The experimental application of groundwater depth to supply irrigation by capillary rise is presented in Figure 2. Treatments consisted of maintaining groundwater depth at 5, 10 and 15 cm-surface. In order to maintain a constant groundwater level, the water height in the column was kept constant, which required daily observation. Crop growth was determined by measuring height as well as number of leaves at 2 weeks after planting. Root length and number of leaves for each treatment were also observed at the end of the experiment.

Figure 2. Experimental application of groundwater depth to supply irrigation water to the crop [Colour figure can be viewed at wileyonlinelibrary.com]

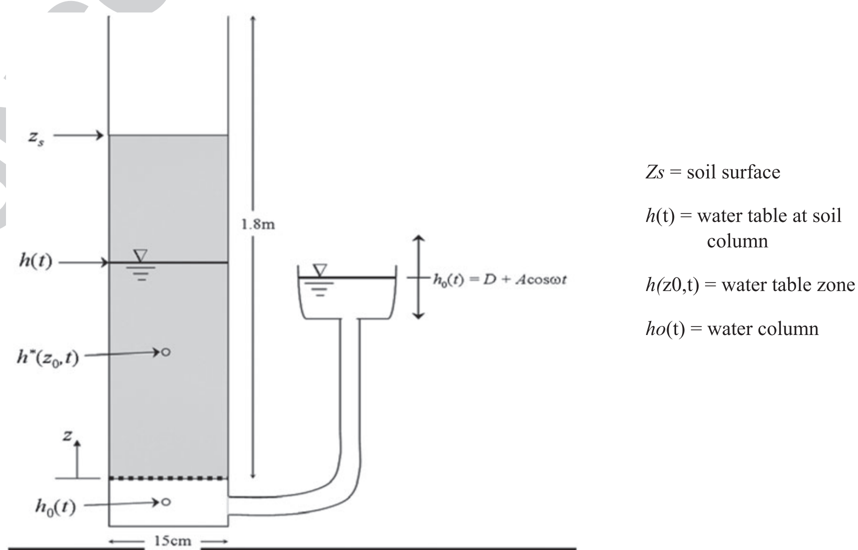
Colour online, B&W in print

To determine the best planting in the field, daily groundwater data were analysed by comparing the greenhouse experimental result of watermelon growth response to shallow groundwater tables in the initial phase. Data analysis of the daily groundwater level was carried out to determine planting potential in the field. The data of daily groundwater level were also compared with rainfall data in 2015 that were obtained from Kenten Climatologic Station in Palembang.

RESULTS AND DISCUSSION

Study of planting potential in tidal lowland area

Watermelon cultivation in tidal lowland areas is highly dependent on the season. Planting in the wet season cannot be implemented due to the very high groundwater level as a



Q15 Figure 1. Experimental set-up of groundwater contribution to crop water requirement (Udom *et al*., 2013) result of rainfall. Figure 3 shows groundwater level observations in the Telang I area in 2009, which indicate that the groundwater was too saturated up to May for cultivation of crops, except for rice. Planting could be done by the end of May or early June with as a consequence that the crops frequently experienced dryness during the generative phase in August.

When structures in the tertiary canals have been installed, then according to Bakri *et al.* (2015) the water management objective for crop cultivation in the period June–September will be water retention within the tertiary canals. If high fresh tidal water can still enter the tertiary canal, then a proper water gate is a stop log with a retention level of 0.50 m from the bottom level of the canal. The stop log height would have to be regulated such that high tidal water can enter the canal and water is held at a minimum of 0.50 m-surface during the low tide period. If an automatic fibre flap gate has been installed, then the gate position during the dry season needs to be before the culvert at the downstream side of the tertiary canal so that high tidal water can enter the canal and the gate will automatically close during the low tide period. However, such gates can easily be damaged and cannot be repaired by the farmers (Imanudin *et al.,* 2016).

Although in November high tidal water can be blocked to prevent it from getting on to the land, high rainfall intensity coupled with insufficient duration of low tide for discharge will result in full canals and it will be difficult to achieve groundwater drawdown. Figure 4 shows data of groundwater-level fluctuation from February to March on Class B land in 2015. The drastic upward movement of the groundwater level was due to rainfall. At that time there were no structures and the tide water could enter the tertiary block, so the land had more excess water and a higher groundwater level or inundation during the wet season. The groundwater level dropped continuously in the case of no rainfall. In addition to the structures in the tertiary canals, in the concerned area a micro water management system

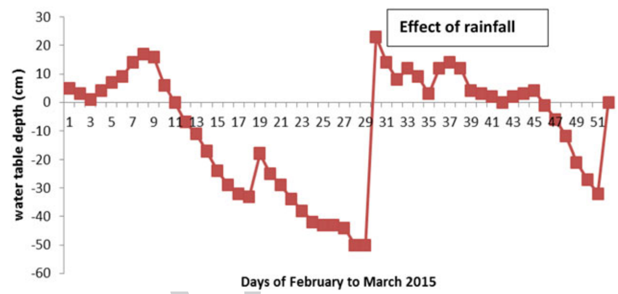


Figure 4. Groundwater level in February and March 2015 under dry conditions [Colour figure can be viewed at wileyonlinelibrary.com]

was installed. The system consists of small canals (called *micro channels*) at 8 m spacing, having a depth of 20 cm. The data in Figure 9 show that the micro water management system was relatively effective in lowering the groundwater level. However, farmers could not do planting in early March because the average depth of the groundwater level was less than 10 cm-surface. Figure 3 also shows that there was flooding for 10–12 days. Direct planting of watermelon seeds could not be done in these conditions and could only be done on the 14th day or in the middle of March.

Planting would have to be done at the end of the wet season in April or as a result of the El Nino effect in 2015 even in March due to the dry conditions. Crop adaptation to dry conditions could start planting in the early growth period in the wet season. The decision to move the planting time forward was made to prevent water deficiency during the generative growth phase. Dry climate conditions in August–September cause moisture content in the root zone to be close to the permanent wilting point due to the decrease of the capillary rise, because the groundwater dropped deeper than 1.50 m-surface. Rainfall started to decrease at the beginning of July and the maximum decrease occurred in the period August–October (Figure 5).

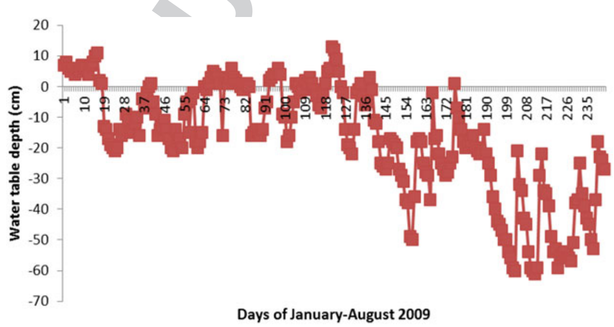


Figure 3. Groundwater level during the January–August period in normal conditions (Imanudin *et al.,* 2010) [Colour figure can be viewed at wileyonlinelibrary.com]

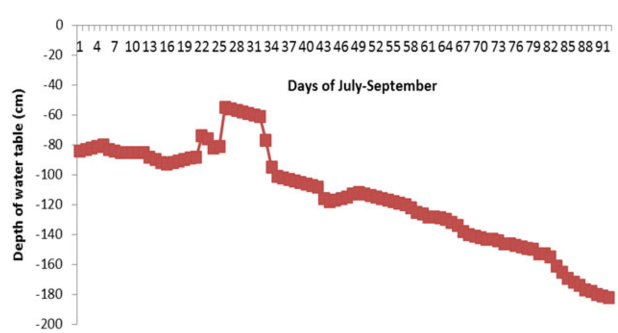


Figure 5. Groundwater level during the dry season of 2015 on Class B land [Colour figure can be viewed at wileyonlinelibrary.com]

Planting intensity can be done two or even three times as an impact of land and water management. In addition, intensive farming can decrease forest and land fires indirectly if the land is properly managed and utilized (Imanudin and Susanto, 2015).

Experiment of watermelon planting under shallow groundwater table conditions

The basic objective of the experiment was to analyse the possibilities for earlier planting of watermelon during the wet season in March or early April. For that reason the experiment was carried out in a greenhouse to identify the crop response to shallow groundwater table conditions.

Crop testing results for two groundwater conditions mentioned above showed that the crop can still grow at a groundwater depth of 5 cm-surface with a less than optimal growth level. Watermelon had already grown on the fourth day with a groundwater depth of 10 cm-surface, but it had not grown with a groundwater depth of 5 cm-surface. Plant height was 5.6 cm and the leaves were still cringe (closed) with uplifted seed skin on the sixth day with a groundwater depth of 10 cm-surface, but stem prospective was just emerging for a groundwater depth of 10 cm-surface. Plant height was 12.1 cm with three leaves on the 17th day with a groundwater depth of 10 cm-surface, whereas it was 8.2 cm with three leaves on the 17th day with a groundwater depth of 5 cm-surface. Average growth rate of the crop until the 17th day for a groundwater depth of 10 cm-surface was 0.71 cm day^{-1} and its value was 0.48 cm day^{-1} for a groundwater depth of 5 cm-surface. A crop growth description is given in Figure 6.

The laboratory experiment was stopped 20 days after planting because it was estimated that the groundwater had dropped more than 20 cm-surface in field conditions. This period was at the end of the wet season (April) when farmers did their planting at the end of March. The plants can be more adaptive to environment conditions during this period. Observations on the 20th day were conducted on watermelon treated with a groundwater table at 15 cm-surface. Plant height was 15.2 cm and it had four leaves. The plants had more leaves with this treatment than those of the 10 and 5 cm-surface treatments.

Average plant height was 0.76 cm for the 15 cm-surface treatment. This value was relatively similar to the result obtained from that of 10 cm-surface. Therefore, watermelon cultivation can be started if field conditions show a groundwater level of 10 cm-surface. A contrasting condition was found with the 5 cm-surface treatment, which showed a cessation of the growth of root elongation. The root length was only 3.1 cm at 20 days after planting, which indicated that root growth avoids a high groundwater table.

Potential time of planting on Class C land

The results from greenhouse experiments also showed that watermelon can be planted under conditions of a shallow groundwater table between 10 and 15 cm-surface, if watermelon is cultivated on Class C land. The water in the tertiary canals can maintain the groundwater table. In tidal lowland areas, then, the planting time can be accelerated to the end of February or planting can be directly conducted after rice harvesting. Planting can be done by using the hole system in which after clearance of rice straw a micro canal is dug every 6–8 m, using a single plough. The planting needs to be done quickly in order to prevent drying out. If planting is done at the end of February or in early March harvesting can be expected by the end of May. The generative phase would be in May. Observation results of the groundwater-level fluctuation showed that planting could be done in early March when the groundwater level was 20–30 cm-surface (Land and Water Management Tidal Lowlands (LWMTL), 2006). Depending on the groundwater level, planting could be done in February, but it is better to do it in early March,

-5 cm -10 cm -15 cm

Figure 6. Visualization of watermelon response to shallow groundwater table conditions (15th day) [Colour figure can be viewed at wileyonlinelibrary.com]

Colour online, B&W in print

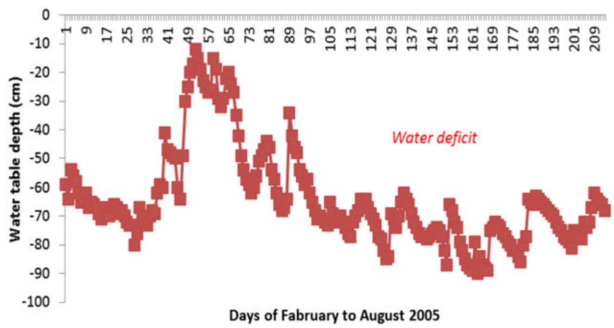


Figure 7. Groundwater table fluctuation in a Class C tidal lowland area (LWMTL, 2006) [Colour figure can be viewed at wileyonlinelibrary.com]

Colour online, B&W in print

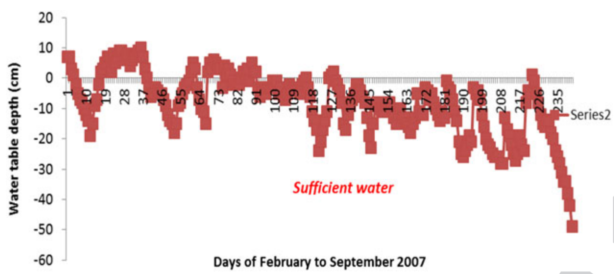


Figure 8. Groundwater fluctuation on Class B land (Imanudin *et al.*, 2010) [Colour figure can be viewed at wileyonlinelibrary.com]

because in February farmers are busy with first-season rice harvesting. Water retention in canals needs to be provided in order to maintain a groundwater table close to the root zone.

The flowering phase in May poses a high risk, because the groundwater table frequently drops to 0.90–1.00 m-surface (Figure 7). Therefore, irrigation would be needed in this phase and be applied twice. Irrigation by pumps would be helpful to pump water from tertiary canals using furrow irrigation. High soil porosity in Class C land may mean that capillary water is not sufficiently available to fulfil the evapotranspiration requirement if the depth of the groundwater table is lower than 1.00 m-surface. This showed that the critical level of the groundwater table is 1.00 m-surface for Class C land, whereas it is at 1.50 m-surface for Class B land, when dominated by clay soil. Analysis results of groundwater table fluctuation showed that watermelon cultivation can be carried on without irrigation on Class B land (Figure 8).

CONCLUSIONS

The following conclusions can be drawn from this study:

- Watermelon has the potential to be developed in tidal lowland areas because it is relatively tolerant to shallow groundwater depth in the initial growth phase. The crop was able to grow at a groundwater depth of 5 cm-surface. Optimum growth was achieved at a groundwater depth of 15 cm-surface. However, field application showed that watermelon can be planted at a groundwater depth of 10 cm-surface. Results of the field study showed that a groundwater depth for Class B–C land had reached 15 cm-surface in March–April. Accelerated planting at the end of March is important in order to prevent dryness during the generative phase, when irrigation by gravity cannot be applied;
- crop adaptation to the groundwater table is dependent on planting time and land category. The crop could be planted in June and be harvested in September without irrigation in Class A and B land. Capillary water on these land classes was sufficient to fulfil the evapotranspiration requirement. However, an earlier planting time in March and harvesting in May–June needs to be conducted on Class C land, because this land had a high soil porosity. Capillary water during the dry season in this soil could not fulfil the evapotranspiration requirement. In June–September the groundwater could reach more than 1.20 m-surface;
- the tertiary canal needs to be equipped with a stop log or flap gate to control the preferred groundwater table. The main option for Class A and B land was drainage, whereas for Class C land it was water retention.

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NOTE

[1]Rp = Indonesian rupiah, 1 Rp = 0.000077 US$, price level 2016.

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DETERMINATION OF PLANTING TIME OF WATERMELON UNDER A SHALLOW GROUNDWATER TABLE IN TIDAL LOWLAND AGRICULTURE AREAS OF SOUTH SUMATRA, INDONESIA†

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ABSTRACT

Watermelon cultivation is one of the appropriate alternatives in order to increase farmers' income from tidal lowland agriculture. Research into crop adaptation to wet soil conditions is required to enable farmers to decide the best planting time under various conditions within the existing land classification. The research to determine crop physiological response during the initial growth period was conducted in a greenhouse. This was combined with field treatments based on groundwater table depths at 15, 10 and 5 cm-surface, respectively. Analysis of crop potential based on the water status conditions in the root zone was conducted by using secondary and primary data (daily records). Results of crop adaptation at shallow groundwater table depth showed that the treatments with groundwater table depth of 10 and 5 cm-surface were not significantly different in terms of plant height, with a size of 12.6 and 12.3 cm, having three leaves. However, it had a significant effect on root length, with a length of 11.9 and 3.1 cm, respectively. Maximum plant height of 15.2 cm and four leaves were found for the treatment with a groundwater table depth of 15 cm-surface. It may be concluded that it is best for farmers to plant at a groundwater table depth of 10 cm-surface. © 2019 John Wiley & Sons, Ltd.

KEY WORDS: tidal lowland; watermelon; groundwater table; drainage

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RÉSUMÉ

La culture de la pastèque est l'une des alternatives appropriées pour augmenter les revenus des agriculteurs issus de l'agriculture des plaines de marée. Des recherches sur l'adaptation des cultures aux conditions de sol humides sont nécessaires pour permettre aux agriculteurs de décider du meilleur moment de plantation dans diverses conditions dans la classification des terres existante. Les recherches visant à déterminer la réponse physiologique des cultures au cours de la période de croissance initiale ont été menées en serre. Ceci a été combiné avec des traitements sur le terrain basés sur la profondeur de la nappe phréatique à 15, 10 et 5 cm de surface respectivement. L'analyse du potentiel des cultures en fonction des conditions de l'état de l'eau dans la zone racinaire a été réalisée à l'aide de données secondaires et primaires (enregistrements quotidiens). Les résultats de l'adaptation des cultures à la profondeur de la nappe phréatique peu profonde ont montré que les traitements avec une profondeur de la nappe phréatique de 10 et 5 cm n'étaient pas significativement différents en termes de hauteur de plants de 12,6 et 12,3 cm, avec trois feuilles. Cependant, il a eu un effet significatif sur la longueur de la racine avec une magnitude de 11,9 et 3,1 cm, respectivement. Une hauteur de plant maximale de 15,2 cm et quatre feuilles a été trouvée pour le traitement avec une profondeur de nappe phréatique de 15 cm. On peut en conclure que les agriculteurs peuvent mieux planter à une profondeur de la nappe phréatique de 10 cm. © 2019 John Wiley & Sons, Ltd.

MOTS CLÉS: plaine de marée; pastèque; nappe phréatique; drainage

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†Détermination de la date de plantation de pastèques en agriculture sous nappe phréatique peu profonde des plaines de marées.

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INTRODUCTION

Tidal lowlands are low-lying, flat coastal plains, with a micro relief of not more than 1.00 m (Schultz *et al.,* 2013). Depending on the relative position of the land to the tide, the following classification has been made by the Directorate of Swamps (1984). There are four hydro-topographic classes:

- Class A is land below low high tide. The land can always receive water from the tide during the dry and wet seasons;
- Class B is land below high tide, but above land in Class A. The land can only receive tide water during the wet season;
- Class C is land not higher than 0.50 m above the highest tide. The water table is lower than 0.50 m-surface. Water supply from high tidal water cannot be provided because it is below the surface. Class C land is therefore highly dependent on rainfall;
- Class D is land above class C (upland soils). The land never receives water from the tide and is suitable for upland crops or plantations. The water table is deeper than 0.50 m-surface.

In tidal lowland areas tertiary canals have the function of collecting and discharging excess water during the wet season and if possible to supply fresh water during the dry season. When stop logs or flap gates are installed in these canals improved water management with a focus on these functions can be established (Suprianto *et al.,* 2010; Imanudin *et al.,* 2016).

Agriculture in tidal lowland areas of Indonesia has faced the problem of land use conversion from food crops to plantation crops. One way to control land use conversion in tidal lowland agriculture is to increase planting intensity. Studies by Imanudin *et al.* (2010, 2011) in tidal lowland in the Telang II area showed that the land had great potential for two or even three crops per year (Schultz *et al.,* 2015). The change of planting pattern from one into two times of planting can bring an equal income compared to that from oil palm. The change of planting pattern from *rice–fallow* into *rice–corn* and *rice–corn–corn* was more profitable (Imanudin and Bakri, 2014). Crop diversification with watermelon provides new prospects for farmers because it can result in a higher income compared to that of an oil palm plantation. The profit gained from watermelon cultivation with duration of 70–90 days can be as high as 30 million Rp/ha.[1] According to Gunawan (2014), if watermelon production is 11 t and the price is 3000 Rp kg^{-1}, then the net profit received by the farmers is about 18.5 million Rp.

Watermelon cultivation is therefore one of the appropriate alternatives in order to increase farmers' income from tidal lowland agriculture. However, information about the minimum depth of the groundwater table for crop planting is very important for farmers to determine the planting date. Therefore, research on crop adaptation to wet soil conditions is required to enable farmers to decide on the best planting time under various conditions within the existing land classification. This paper describes the experimental research on watermelon under greenhouse control conditions and validated by using groundwater data that have been recorded in the Telang area, South Sumatra.

BACKGROUND

The value of the benefit/cost (B/C) ratio is highly dependent on the cost of agricultural inputs. Research in Iran showed that there the B/C ratio of watermelon plants was 2.6 (Namdari, 2011). Adeboye *et al.* (2011) reported that the B/C ratios in Nigeria are lower at only 2.3 because of the costs of transportation and fertilizer. At present the largest watermelon-producing country is China. However, Indonesia is among the top 20 countries exporting the fruit A watermelon cultivation effort in the lowlands is considered to be useful as an option for farm enterprise diversification.

Wang *et al.* (2017) reported that irrigation is needed for crop cultivation if rainfall during the growing season is less than 120 mm. They stated that 68 mm irrigation water will increase production by 46%. They also stated that irrigation water coupled with mulch can increase production by 11.4 t ha^{-1} compared to cultivation without mulch.

Evapotranspiration is strongly influenced by changes in groundwater depth. The closer the groundwater is to the soil surface, the higher the evapotranspiration. In lowland areas plant growth is highly dependent on water supply from capillary water movement. Results of a study by Singh *et al.* (2006) on *Typic Haplustalf* soil with a clay content of 45% showed capillary water movement of 18.7 mm day^{-1} at a groundwater depth of 0.90 m-surface. The groundwater contribution decreased to 10.7 mm day^{-1} at a groundwater depth of 1.20 m-surface. Results of a study by Singh *et al.* (2006) showed that groundwater contribution was 10.7 mm day^{-1} if the groundwater table depth was 1.20 m-surface for dominated clay textural soil. On the other hand, capillary water contribution was 4.8 mm day^{-1} if the groundwater table was at 0.74 m-surface and 2.5 mm/day if it was at 1.00 m-surface for sandy loam soil (Udom *et al.*, 2013). The groundwater contribution in sandy clay soil at a groundwater depth of 0.74 m-surface was 4.76 mm day^{-1} and 2.45 mm day^{-1} at a groundwater depth of 1.00 m-surface (Udom *et al.*, 2013). These data showed that groundwater movement at 1.00–1.20 m-surface is sufficient to fulfil the evapotranspiration requirement. However, the crop will require additional irrigation water if the groundwater is located deeper than 2.00 m-surface. Therefore, the water retention function to keep the groundwater table at 1.00–1.30 m-surface is very important if farmers cultivate crops during the dry season. Karimova *et al.* (2014) reported for the case of loamy clay soil that a groundwater table at 1.50 m-surface resulted in evapotranspiration of 47% and at 3 m-surface only of 23%. This finding showed that the crop required irrigation for maximum evapotranspiration at those positions. As reported by Pelletier *et al.* (2015), at a groundwater depth of 0.60 m-surface almost 70–80% irrigation water can be saved. According to Agele *et al.* (2015), variation in the contribution of capillary water to groundwater storage is a function of the groundwater depth. A high capillary rise is obtained when the depth of the groundwater table is within the threshold of the capillary rise during the harvesting period and evapotranspiration can be entirely sourced from groundwater. The simulations conducted by Gao *et al.* (2017) suggest that at a groundwater depth of 1.00 m-surface 40% of the evapotranspiration from plants is supplied from capillary water. Reported by Saraiva et al., (2018) to reduce water requirements in watermelon cultivation, mulch technology was successfully applied. Through that technology the production of watermelon reaches 73.66 Mg ha^{-1} with an irrigation water level of 314 mm.

The ideal conditions for crop growth are an available water condition between field capacity and permanent wilting point. Crop growth at the initial phase will be disturbed if the soil moisture is at 75% of exhausted available water, whereas optimum crop growth is at 50% of exhausted available water (Modi and Zulu, 2012). A crop which is flooded during a short time will experience hypoxia (lack of O_2). Hypoxia usually occurs if parts of the crop roots are flooded (the crown part is not flooded) or when the crop is flooded for a long time but crop roots are located near the soil surface. If all parts of a crop are flooded, then the roots are located deeper in the soil and experience flooding for a longer time so that the crop is in anoxia condition (an environment without O_2). The anoxia condition occurs 6–8 h after flooding because O_2 is suppressed by water and the rest of the O_2 is utilized by microorganisms. The left-over O_2 content within the soil during flooded conditions with a crop is used up faster because the O_2 diffusion rate within a wet soil is 10 000 times slower than that in air (Amstrong, 1979). Conditions of hypoxia or anoxia not only prevent N fixation, but also distribution of N and other minerals, which in turn impede root growth and nodulation. Leaves will experience yellowing followed by leaf fall due to insufficient transportation of N and minerals into the crown part. Scott and Fisher (1989) reported that flooding effects were indicated by leaf yellowing, leaf fall at the lowest joint, dwarf growth and a decrease of dry matter weight and crop yield. According to Hapsari and Adie (2010), results of their study on soybeans showed that yield losses at the vegetative phase were generally lower than during the reproductive phase, having values of 17–43 and 50–56% respectively. The magnitude of yield losses was dependent on crop variety, crop growth phase, flooding period, soil texture and the existence of crop weeds and diseases. According to Pasaribu *et al.* (2013), under tropical climatic conditions in *ultisol* soil the crop water requirement for watermelon is 2.8 mm day^{-1} for the initial growth phase, 6.2 mm day^{-1} for the middle growth phase and 4.4 mm day^{-1} for the final growth phase, respectively.

Tidal lowland areas with a shallow groundwater table have a high potential for watermelon cultivation. The groundwater contribution through capillary flow is sufficient to provide the crop water requirement (Imanudin and Bakri, 2014). This condition has the advantage that irrigation is not needed, resulting in cost saving. Imanudin *et al.* (2010) stated that controlled drainage is the best option to maintain preferred water levels in lowland areas. Farmers would have to install hydraulic structures in tertiary canals in order to control the open water table at levels in such a way that optimal growth conditions for the crops are created. However, if planting is delayed at flowering stage during the dry season and the groundwater depth exceeds 1.50 m-surface, irrigation by pumping needs to be provided (Singh *et al.,* 2006). In addition, a long period of flooding results in abiotic stress of the crop, which affects the sprout growth rate, seed development and subsequently affects crop growth and development, especially during the initial growth period (Dat *et al.,* 2000). The food crop is capable of tolerating a water content level which exceeds the field capacity by 25% (Prawoto *et al.,* 2005).

In the Telang area during the November–January period the water is generally above the soil surface with a 10–20 cm inundation height. In this period rice is planted (first season), starting in February the water level is gradually lowered to a depth of 20–30 cm-surface and the rice reaches the harvest period (Imanudin and Bakri, 2014). According to Bakri *et al.* (2014) the groundwater levels after rice harvesting are still high enough for the cultivation of a second crop. If there are tertiary gates then they will be operated to achieve maximum drainage. In the March–April period, groundwater levels in tidal lowlands that have a Class B hydro-topography are in the range of 20–30 cm-surface. Thus the soil moisture in the root zone is still too wet for a second crop like corn. However watermelon plants could be planted by the end of April.

Based on the above discussion, applied research was considered to be required to determine watermelon crop response at the initial phase to shallow groundwater table conditions.

MATERIALS AND METHODS

The research was conducted from March to April 2016 in the greenhouse at the Agroecotechnology Department, Faculty of Agriculture, Sriwijaya University. Data of daily groundwater level from secondary data and direct observations were used to analyse the planting time. The secondary data were obtained in tidal lowland pilot project areas in the Telang I area. The direct observations were done on a tertiary plot in the Telang II area in 2015 (Imanudin *et al.,* 2010).

Materials and equipment used in this study were soil, having a sandy loam texture, watermelon seeds, water and aqua bottles. Equipment for groundwater level control was obtained by using the continuous flow system (Figure 1) in which the groundwater level is kept in equilibrium with that in a reservoir using the principle of connected vessels. The experimental application of groundwater depth to supply irrigation by capillary rise is presented in Figure 2. Treatments consisted of maintaining groundwater depth at 5, 10 and 15 cm-surface. In order to maintain a constant groundwater level, the water height in the column was kept constant, which required daily observation. Crop growth was determined by measuring height as well as number of leaves at 2 weeks after planting. Root length and number of leaves for each treatment were also observed at the end of the experiment.

To determine the best planting in the field, daily groundwater data were analysed by comparing the greenhouse experimental result of watermelon growth response to shallow groundwater tables in the initial phase. Data analysis of the daily groundwater level was carried out to determine planting potential in the field. The data of daily groundwater level were also compared with rainfall data in 2015 that were obtained from Kenten Climatologic Station in Palembang.

Figure 2. Experimental application of groundwater depth to supply irrigation water to the crop [Colour figure can be viewed at wileyonlinelibrary.com]

RESULTS AND DISCUSSION

Study of planting potential in tidal lowland area

Watermelon cultivation in tidal lowland areas is highly dependent on the season. Planting in the wet season cannot be implemented due to the very high groundwater level as a result of rainfall. Figure 3 shows groundwater level observations in the Telang I area in 2009, which indicate that the groundwater was too saturated up to May for cultivation of crops, except for rice. Planting could be done by the end

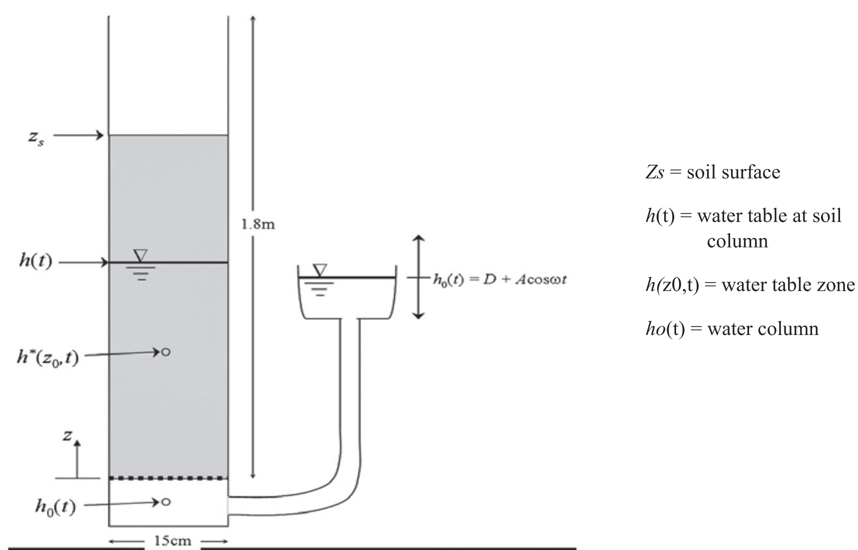

Figure 1. Experimental set-up of groundwater contribution to crop water requirement (Udom *et al*., 2013)

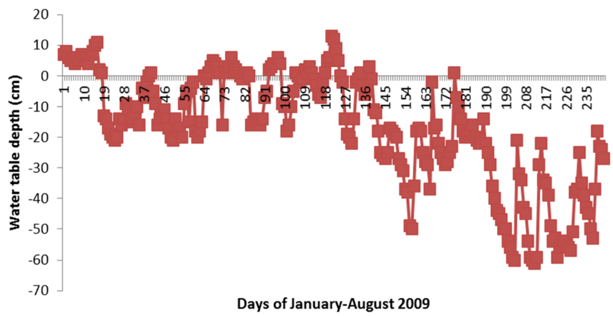

Figure 3. Groundwater level during the January–August period in normal conditions (Imanudin *et al.,* 2010) [Colour figure can be viewed at wileyonlinelibrary.com]

of May or early June with as a consequence that the crops frequently experienced dryness during the generative phase in August.

When structures in the tertiary canals have been installed, then according to Bakri *et al*. (2015) the water management objective for crop cultivation in the period June–September will be water retention within the tertiary canals. If high fresh tidal water can still enter the tertiary canal, then a proper water gate is a stop log with a retention level of 0.50 m from the bottom level of the canal. The stop log height would have to be regulated such that high tidal water can enter the canal and water is held at a minimum of 0.50 m-surface during the low tide period. If an automatic fibre flap gate has been installed, then the gate position during the dry season needs to be before the culvert at the downstream side of the tertiary canal so that high tidal water can enter the canal and the gate will automatically close during the low tide period. However, such gates can easily be damaged and cannot be repaired by the farmers (Imanudin *et al.,* 2016).

Although in November high tidal water can be blocked to prevent it from getting on to the land, high rainfall intensity coupled with insufficient duration of low tide for discharge will result in full canals and it will be difficult to achieve groundwater drawdown. Figure 4 shows data of groundwater-level fluctuation from February to March on Class B land in 2015. The drastic upward movement of the groundwater level was due to rainfall. At that time there were no structures and the tide water could enter the tertiary block, so the land had more excess water and a higher groundwater level or inundation during the wet season. The groundwater level dropped continuously in the case of no rainfall. In addition to the structures in the tertiary canals, in the concerned area a micro water management system was installed. The system consists of small canals (called *micro channels*) at 8 m spacing, having a depth of 20 cm. The data in Figure 4 show that the micro water management system was relatively effective in lowering the groundwater level. However, farmers could not do planting in early March because the average depth of the groundwater level was less than 10 cm-surface. Figure 3 also shows that there was flooding for 10–12 days. Direct planting of watermelon seeds could not be done in these conditions and could only be done on the 14th day or in the middle of March.

Planting would have to be done at the end of the wet season in April or as a result of the El Nino effect in 2015 even in March due to the dry conditions. Crop adaptation to dry conditions could start planting in the early growth period in the wet season. The decision to move the planting time forward was made to prevent water deficiency during the generative growth phase. Dry climate conditions in August–September cause moisture content in the root zone to be close to the permanent wilting point due to the decrease of the capillary rise, because the groundwater dropped deeper than 1.50 m-surface. Rainfall started to decrease at the beginning of July and the maximum decrease occurred in the period August–October (Figure 5).

Cropping intensity on tidal lowland reclamation areas can be done two or even three times as an impact of land and water management. Farmers can grow rice-rice-corn in a year. In addition, intensive farming can decrease forest and land fire indirectly if the land is properly managed and utilized (Imanudin and Susanto, 2015).

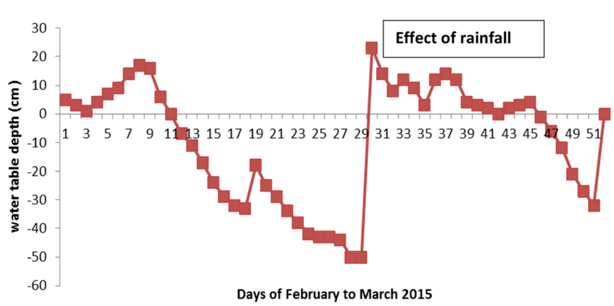

Figure 4. Groundwater level in February and March 2015 under dry conditions [Colour figure can be viewed at wileyonlinelibrary.com]

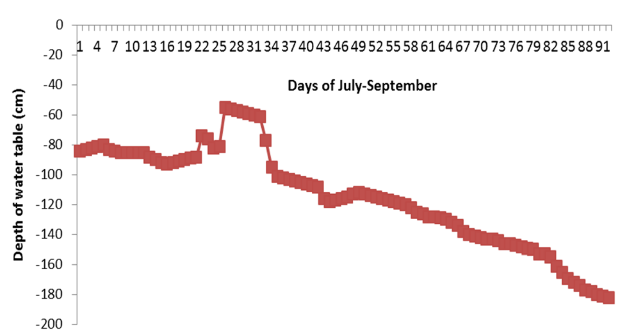

Figure 5. Groundwater level during the dry season of 2015 on Class B land [Colour figure can be viewed at wileyonlinelibrary.com]

Experiment of watermelon planting under shallow groundwater table conditions

The basic objective of the experiment was to analyse the possibilities for earlier planting of watermelon during the wet season in March or early April. For that reason the experiment was carried out in a greenhouse to identify the crop response to shallow groundwater table conditions.

Crop testing results for two groundwater conditions mentioned above showed that the crop can still grow at a groundwater depth of 5 cm-surface with a less than optimal growth level. Watermelon had already grown on the fourth day with a groundwater depth of 10 cm-surface, but it had not grown with a groundwater depth of 5 cm-surface. Plant height was 5.6 cm and the leaves were still bud (closed) with uplifted seed skin on the sixth day with a groundwater depth of 10 cm-surface, but prospective stem was just emerging for a groundwater depth of 10 cm-surface. Plant height was 12.1 cm with three leaves on the 17th day with a groundwater depth of 10 cm-surface, whereas it was 8.2 cm with three leaves on the 17th day with a groundwater depth of 5 cm-surface. Average growth rate of the crop until the 17th day for a groundwater depth of 10 cm-surface was 0.71 cm day^{-1} and its value was 0.48 cm day^{-1} for a groundwater depth of 5 cm-surface. A crop growth description is given in Figure 6.

The laboratory experiment was stopped 20 days after planting because it was estimated that the groundwater had dropped more than 20 cm-surface in field conditions. This period was at the end of the wet season (April) when farmers did their planting at the end of March. The plants can be more adaptive to environment conditions during this period. Observations on the 20th day were conducted on watermelon treated with a groundwater table at 15 cm-surface. Plant height was 15.2 cm and it had four leaves. The plants had more leaves with this treatment than those of the 10 and 5 cm-surface treatments.

Average plant height was 0.76 cm for the 15 cm-surface treatment. This value was relatively similar to the result obtained from that of 10 cm-surface. Therefore, watermelon cultivation can be started if field conditions show a groundwater level of 10 cm-surface. A contrasting condition was found with the 5 cm-surface treatment, which showed a cessation of the growth of root elongation. The root length was only 3.1 cm at 20 days after planting, which indicated that root growth avoids a high groundwater table.

Potential time of planting on Class C land

The results from greenhouse experiments also showed that watermelon can be planted under conditions of a shallow groundwater table between 10 and 15 cm-surface, if watermelon is cultivated on Class C land. The water in the tertiary canals can maintain the groundwater table. In tidal lowland areas, then, the planting time can be accelerated to the end of February or planting can be directly conducted after rice harvesting. Planting can be done by using the hole system in which after clearance of rice straw a micro canal is dug every 6–8 m, using a single plough. The planting needs to be done quickly in order to prevent drying out. If planting is done at the end of February or in early March harvesting can be expected by the end of May. The generative phase would be in May. Observation results of the groundwater-level fluctuation showed that planting could be done in early March when the groundwater level was 20–30 cm-surface (Land and Water Management Tidal Lowlands (LWMTL), 2006). Depending on the groundwater level, planting could be done in February, but it is better to do it in early March, because in February farmers are busy with first-season rice harvesting. Water retention in canals needs to be provided in order to maintain a groundwater table close to the root zone.

-5 cm -10 cm -15 cm

Figure 6. Visualization of watermelon response to shallow groundwater table conditions (15th day) [Colour figure can be viewed at wileyonlinelibrary.com]

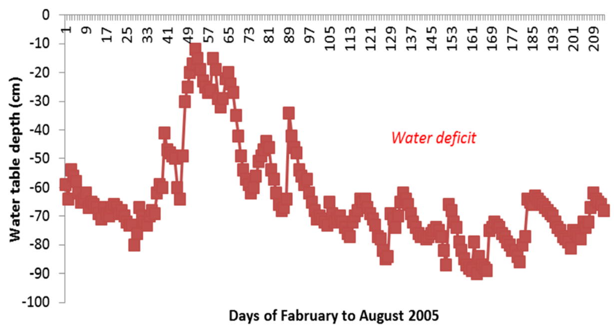

Figure 7. Groundwater table fluctuation in a Class C tidal lowland area (LWMTL, 2006) [Colour figure can be viewed at wileyonlinelibrary.com]

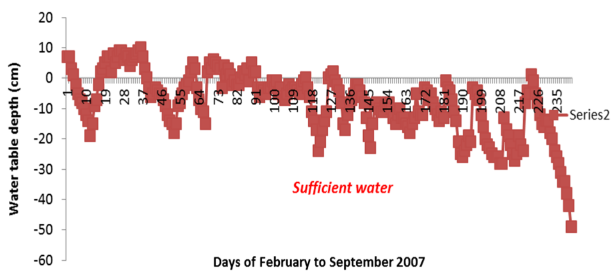

Figure 8. Groundwater fluctuation on Class B land (Imanudin *et al.,* 2010) [Colour figure can be viewed at wileyonlinelibrary.com]

The flowering phase in May poses a high risk, because the groundwater table frequently drops to 0.90–1.00 m-surface (Figure 7). Therefore, irrigation would be needed in this phase and be applied twice. Irrigation by pumps would be helpful to pump water from tertiary canals using furrow irrigation. High soil porosity in Class C land may mean that capillary water is not sufficiently available to fulfil the evapotranspiration requirement if the depth of the groundwater table is lower than 1.00 m-surface. This showed that the critical level of the groundwater table is 1.00 m-surface for Class C land, whereas it is at 1.50 m-surface for Class B land, when dominated by clay soil. Analysis results of groundwater table fluctuation showed that watermelon cultivation can be carried on without irrigation on Class B land (Figure 8).

CONCLUSIONS

The following conclusions can be drawn from this study:

- Watermelon has the potential to be developed in tidal lowland areas because it is relatively tolerant to shallow groundwater depth in the initial growth phase. The crop was able to grow at a groundwater depth of 5 cm-surface. Optimum growth was achieved at a groundwater depth of 15 cm-surface. However, field application showed that watermelon can be planted at a groundwater depth of 10 cm-surface. Results of the field study showed that a groundwater depth for Class B–C land had reached 15 cm-surface in March–April. Accelerated planting at the end of March is important in order to prevent dryness during the generative phase, when irrigation by gravity cannot be applied;
- crop adaptation to the groundwater table is dependent on planting time and land category. The crop could be planted in June and be harvested in September without irrigation in Class A and B land. Capillary water on these land classes was sufficient to fulfil the evapotranspiration requirement. However, an earlier planting time in March and harvesting in May–June needs to be conducted on Class C land, because this land had a high soil porosity. Capillary water during the dry season in this soil could not fulfil the evapotranspiration requirement. In June–September the groundwater could reach more than 1.20 m-surface;
- the tertiary canal needs to be equipped with a stop log or flap gate to control the preferred groundwater table. The main option for Class A and B land was drainage, whereas for Class C land it was water retention.

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NOTE

[1]Rp = Indonesian rupiah, 1 Rp = 0.000077 US$, price level 2016.

