INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
21–0271/2022/28–1–7–16
DOI: 10.17957/IJAB/15.1946
http://www.fspublishers.org

Full Length Article

Evaluating Responses of Tropical Lowland Cabbage to Early Transplanting and Short-Term Drought Prior to Cultivation at Riparian Wetlands during Dry Season

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Received 03 March 2021; Accepted 29 October 2021; Published 22 July 2022

Abstract

Water source for agricultural activities can be very limited at tropical riparian wetlands during dry season. This seasonal drought condition and flooding occurrence during rainy season limits agricultural activity to only single rice cultivation annually, starting after flood water has almost fully subsided. This study was focused on intensifying agricultural activity at the wetland during dry season and creating successful cabbage cultivation as soon as after rice has been harvested. Appropriate transplanting practice was identified and tolerability of cabbage plant to drought stress prior to and during head development was evaluated. Results of this study indicated that cabbage seedlings should be transplanted at 3 weeks after sowing (WAS) for early harvest and higher head yield. Cabbage was able to tolerate short-term drought stress prior to and during head development. Leaf water content significantly dropped after 4 days of drought stress; however, cabbage could recuperate and head yield was not significantly affected. Leaf length and width can be used as accurate predictor for leaf area. Furthermore, canopy area at 5 WAS, size of the largest leaf at 7 WAS, and leaf length at 9 WAS can be used as predictors for head yield, especially head fresh weight; however, the most accurate prediction was using leaf length at 9 WAS or just before head initiation. Based on results of this study, cultivation of lowland cabbage was promising during dry season at tropical riparian wetlands.

Keywords: Canopy area; Head yield; Leaf area; Seedling age; Short-term drought; Yield prediction

Introduction

Availability of tropical lowland cabbage varieties has opened opportunity for local farmers to increase production of this leafy vegetable; otherwise, cabbage production can only be cultivated at very limited area of highlands. Total acreage of lowlands suitable for agriculture was very significant compared to acreage of non-conservation highlands in Indonesia. At present, riparian wetlands in Indonesia has not been intensively cultivated, especially during dry season after rice crop has been harvested (Lakitan *et al.* 2018; 2019). Therefore, prior to introducing cabbage cultivation to the wetlands, adaptability of this vegetable to gradual soil drying which can cause drought stress to the plant should be evaluated; specifically, during late stage of cabbage growth, *i.e*., prior to and during head development. It should be recognized that water availability for agriculture activities during dry season at riparian wetland can be very inadequate (Garssen *et al.* 2014; Ameli and Creed 2019; Albano *et al.* 2020).

Another strategy for minimizing direct exposure to drought stress at riparian wetlands is by growing cabbage plant as early as possible after rice harvesting. Rice is a highly prioritized crop for wetland farmers so that other crops can only be grown after rice crop has been harvested (Chen *et al.* 2015; Ria *et al.* 2020). This strategy includes preparing cabbage seedling at 3 to 5 weeks before rice harvesting such that soon after rice has been harvested, cabbage seedlings could be transplanted to the same rice field. Most of the time before rice harvesting, flood water at paddy field has long been diminished, especially at the short-term flooded riparian wetland type, *i.e*., flooded for less than three months annually (Cabezas *et al.* 2011; Junk *et al.* 2011). Objectives of this research were to evaluate performance of cabbage plants using seedlings transplanted at 3, 4 and 5 weeks after sowing (WAS) and response to drought stress prior to or during head development.

To cite this paper: Lakitan B, K Kartika, N Pratiwi (2022). Evaluating responses of tropical lowland cabbage to early transplanting and short-term drought prior to cultivation at riparian wetlands during dry season. *Intl J Agric Biol* 28:7–16

Materials and Methods

Materials and cultivation practice

Cabbage cultivar used in this study was a hybrid F1 Sehati variety; specially breed for its adaptation to tropical lowland ecosystem. Cabbage seeds were soaked in water for one hour prior to be sown in seedling treys containing the growing substrate. Growing substrate used in this study was a mix of soil and chicken manure with ratio 3:2 v/v. Seeds were sown in each cell of the seedling trey. Three seeds were sown in each cell of the trey; however, only one vigorous seedling was selected during transplanting. This procedure was conducted for increasing uniformity of seedlings used in this study.

Selected seedlings were transplanted into 30 cm diameter pots up to 25 cm height. The pots have four drainage holes at bottom and four side holes at height of 25 cm from base of the pot as direct outlets for surface water for preventing waterlogging during heavy rainfall. This study was conducted outdoor.

Treatments and measured parameters

Seedling ages at time of transplanting were set as treatments, *i.e.*, at 3, 4 and 5 weeks after sowing (WAS). Each seedling-age population was split into two drought stress treatments, *i.e.*, exposed during head initiation, indicated by young leaves started to bend inward at 63 to 67 days after sowing (DAS) and during head enlargement at 91 to 95 DAS. Drought stress exposures were conducted in a mini greenhouse (4 m x 6 m) to avoid rainfall. Level of stress was evaluated by comparing some measured morphological traits during drought exposure between treated and daily-watered control plants. Data were collected at around midday and analyzed using pairwise comparison procedure. Drought stress exposure was terminated after soil moisture had dropped near 10 percent.

Measured parameters and data collection

Data were collected during growth and at harvest. Measured growth parameters included canopy area, leaf length, leaf width, leaf area, sun-lighted canopy area, soil moisture and specific leaf water content (SLWC). Canopy area at early vegetative growth, up until 7 WAS and before leaves overlapped occurred, was directly measured using digital image analyzer developed by Easlon and Bloom (2014). Meanwhile sun-lighted canopy area was measured after overlapping amongst leaves had occurred. Leaf length and width were measured and used as predictors in developing models for leaf area estimation. The models were validated with results of direct leaf area measurement. Soil moisture was daily measured for monitoring drought stress during exposure period using soil moisture meter (Lutron PMS-714, Lutron Electronic Enterprise Co., Ltd., Taiwan). SLWC were calculated according to the procedure described by Meihana *et al.* (2017). Parameters measured at harvest included days to harvest, head yield, head volume, head density, fresh yield, dry shoot biomass, and head water content. Head density was calculated based on ratio between head fresh weight per volume.

Developing models for leaf area estimation

Leaves used in this estimation models were limited to open, unfolded leaves, *i.e.*, not including leaves that tightly wrapped the head. Leaf length and width were used as predictors. Measurement was done using flexible metering tape since cabbage leaf is not properly flat. Two regression models selected were power and zero-intercept quadratic if only single predictor was used, i.e., leaf length (L) or width (W); and simple linear model was added if dual predictor of L × W was selected. Development and validation of models was done according to the protocol described by Lakitan *et al.* (2017).

Statistical analysis

Collected data were analyzed using the analysis of variance, followed by mean comparison among the treatment means using the least squared difference at $P < 0.05$. Relationship between two measured parameters was evaluated based on regression and correlation procedures.

Results

Effects of early seedling transplantation

Age of seedling at transplantation is a crucial factor in cultivation of annual vegetable crops. Early transplanting deals with tiny and fragile seedling, whereas keeping seedling at nursery for longer period could halt seedling growth and cause etiolation due to high seedling density in limited nursery space. In this study, transplanting of cabbage seedlings as early as 3 weeks after sowing (WAS) consistently gave clear advantage over later transplanting time (4 or 5 WAS) as indicated by larger canopy area of earlier transplanted seedlings (3 WAS), especially during early vegetative growth phase, *i.e.*, 5 to 7 WAS (Fig. 1).

Leaf area estimation models

Cabbage is a leafy vegetable; therefore, leaf is a biologically and commercially important organ. Larger leaf and canopy area in cabbage most likely produce larger head. For continuous monitoring of plant growth, a non-destructive approach should be used in measuring leaf and canopy areas. Models for accurately estimating leaf or canopy area can be created based on correlation between leaf or canopy area and non-destructively measurable predictors such as leaf length and/or width. Some regression models had been

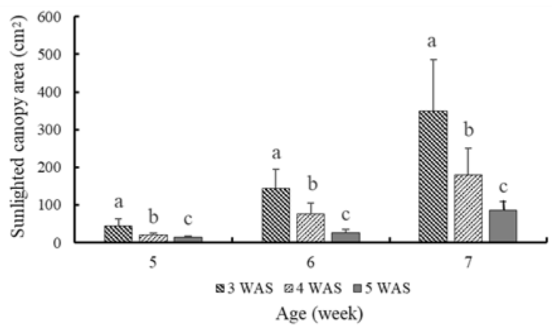

Fig. 1: Cabbage plants were transplanted earlier at 3 WAS exhibited larger canopy at ages of 5, 6 and 7 weeks than those transplanted at 4 and 5 WAS

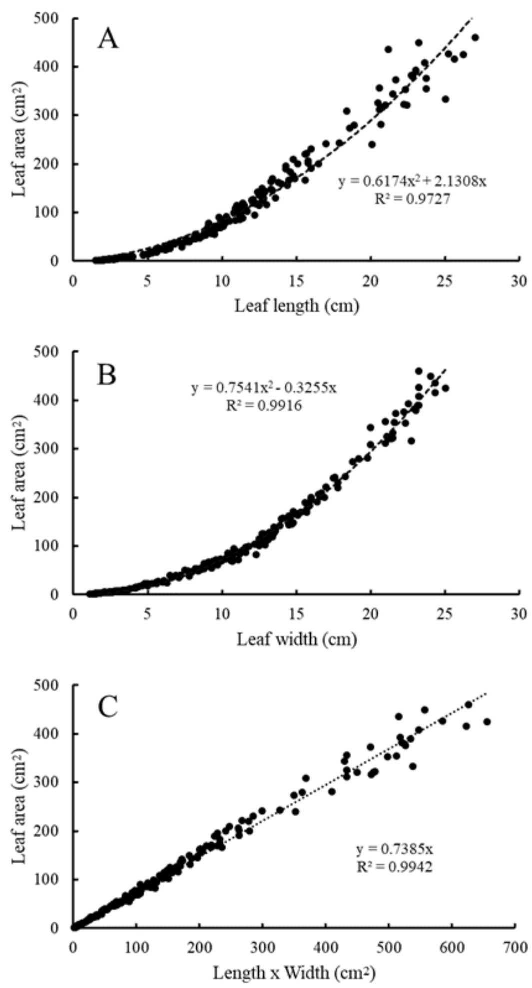

Fig. 2: Leaf length (A), width (B) and length x width (C) were very reliable predictors for estimating leaf area in tropical lowland cabbage prior to heading development. Models used were zero-intercept quadratic (A and B) and linear (C) regressions

proven to be highly accurate ($R^2 > 0.99$) in predicting leaf area (Fig. 2) and canopy area using leaf length (L), leaf width (W), or combination of leaf length and width (L x W) as predictors.

In case of canopy area estimation, accuracy of L x W as predictor diminished after leaves had heavily overlapped, *i.e*., at 7 WAS (Fig. 3). Strong correlation at 5 and 6 WAS indicated that leaves of cabbage plants had not been overlapped; while weak correlation at 7 WAS indicates that the leaves had been overlapped.

Predicting head yield based on leaf and canopy size

It was assumed that cabbage plant with larger canopy would produce larger head, therefore, higher yield. It was also beneficial if the yield could be predicted as early as possible so that farmer could make early decision on how to manage and/or what to expect on his/her current growing season. At early vegetative growth, *i.e*., 5 WAS, canopy area was a good representation for whole plant size; therefore, it was used to predict head yield. Results of this study indicated that canopy area at 5 WAS exhibited a clear trend that cabbage plant with larger leaf area would produce higher yield, i.e., heavier head fresh weight and larger head volume (Fig. 4). Yet, the correlations were not very strong. Cabbage plant was harvested at 15 WAS, therefore, there was 10-week prediction gap. With this 10-week span, variable micro-agro-climatic conditions could be faced by each individual plant.

At 7 WAS, surface area of the selected largest leaf was used and compared with canopy area as predictor for head yield in cabbage plant. Since the leaf was kept attached to the plant, *i.e*., non-destructive measurement, surface area was estimated using linear regression model with L x W as predictor (see Fig. 2 panel C). From the comparison, surface area of the largest leaf of cabbage plant was a better predictor for head fresh weight and volume than canopy area did at 7 WAS (Fig. 5). It also clearly shown that canopy area was not a good predictor for yield after overlapping amongst leaves within the canopy had been heavily occurred. Shorter span between time of predicting and predicted occurrence increased reliability of the prediction. Furthermore, accuracy of prediction in cabbage head was higher on fresh weight than on volume.

Cabbage has very short petiole. Leaf length in this case is basically measurement of leaf midrib length. Measurement at 9 WAS is the last chance to non-destructively measure length and width of cabbage leaf since, afterward, the leaves start to bend-in to form the head. Leaf length and width were separately used as predictor for head fresh weight and head volume. Leaf length was better that leaf width in predicting both head fresh weight and head volume (Fig. 6). The comparison was based on value of coefficient determination. Consistently, it was found that prediction of fresh weight was more accurate than prediction of head volume. The less accurateness in predicting head volume was associated with variable density of cabbage head.

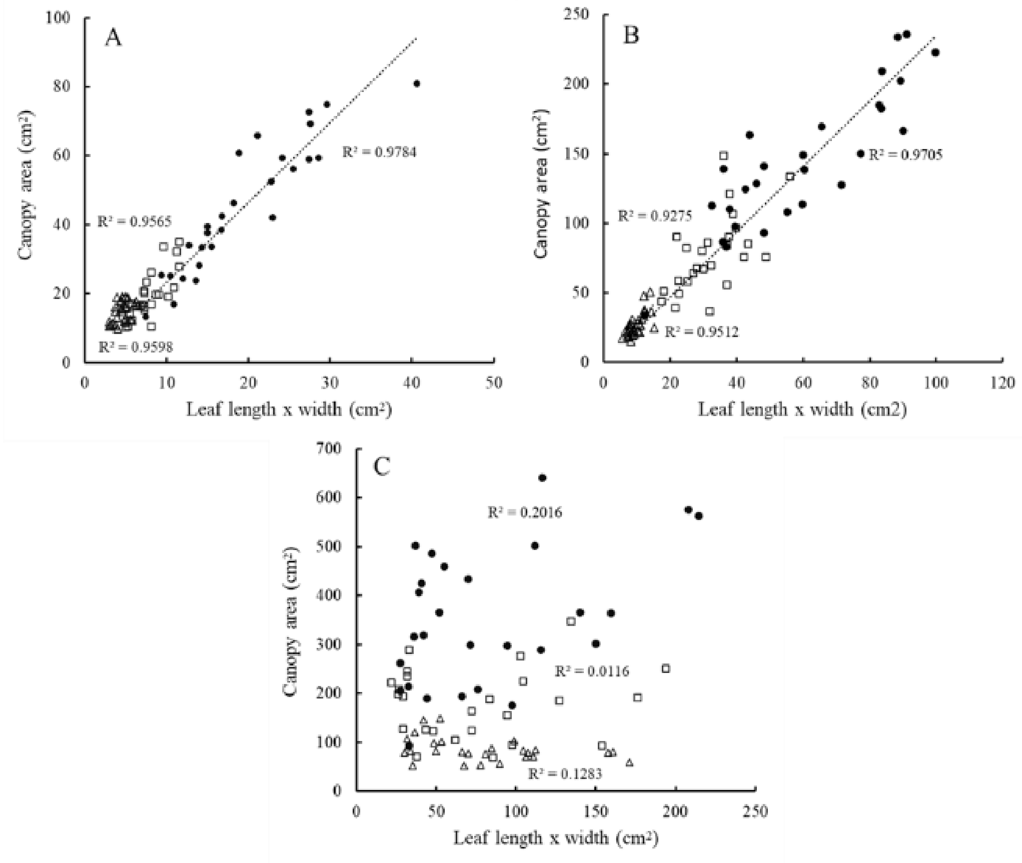

Fig. 3: Predicting canopy area in cabbage plants at age of 5 weeks (A), 6 weeks (B) and 7 weeks (C) using the leaf length x width as predictor. Solid circle, open square, and open triangle represent of plants transplanted at 3 WAS, 4 WAS, and 5 WAS, respectively

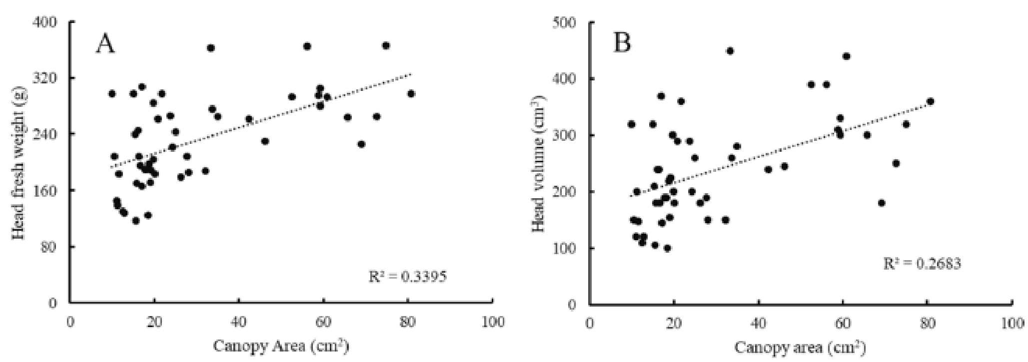

Fig. 4: Predicting head fresh weight (A) and volume (B) based on canopy area at 5 weeks after sowing

Based on three different times of predicting and four different predictors used, it can be concluded that the most reliable prediction for head fresh weight in cabbage plant is by using length of the largest leaf as predictor and measured at 9 WAS, *i.e*., shortly prior to head initiation.

Short term drought caused temporary leaf wilting but did not affect head yield

Soil moisture significantly dropped after 4 consecutive days without water supply in both water stress treatments, *i.e*., prior to (Week 7) and during (Week 13) head developments. Soil moisture gradually decreased to nearly 10% during water stress treatment prior to heading for cabbage plants transplanted at 3 and 4 WAS and to above 14% for cabbage transplanted at 5 WAS. However, soil temperature was not significantly affected by drought (Fig. 7). All cabbage plants treated with water stress, regardless timing of transplanting or stress imposed, all exhibited severe leaf wilting (Fig. 8) but all were able to recover on the next day after stress treatment was terminated.

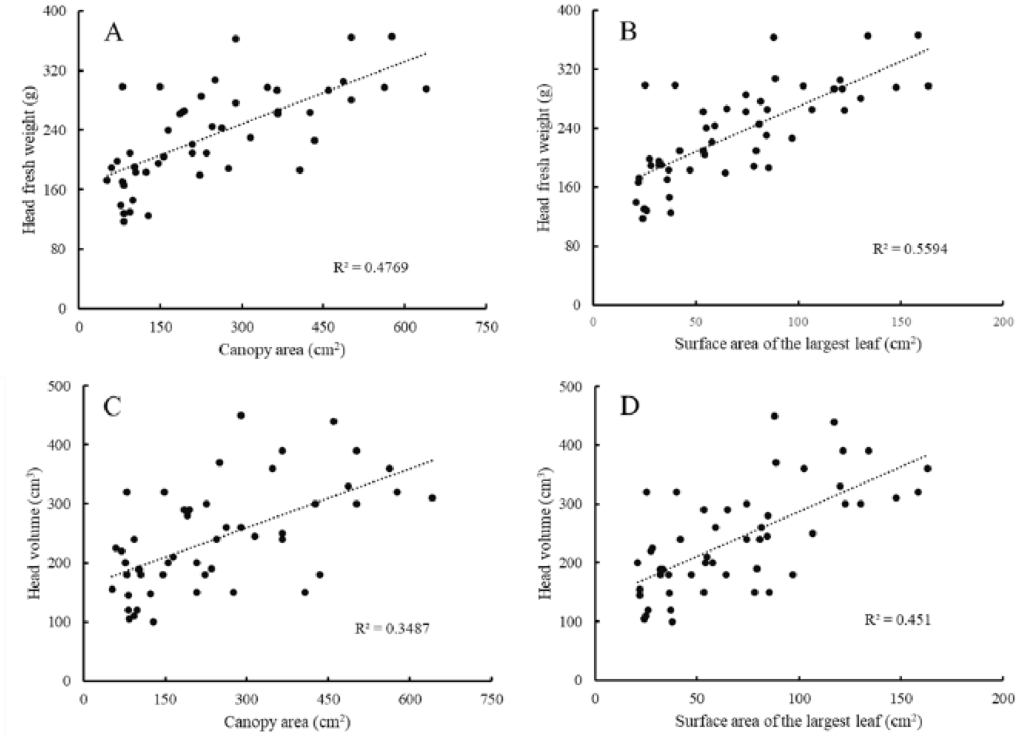

Fig. 5: Predicting head fresh weight (A and B) and volume (C and D) based on canopy and surface area of the largest leaf at 7 weeks after sowing

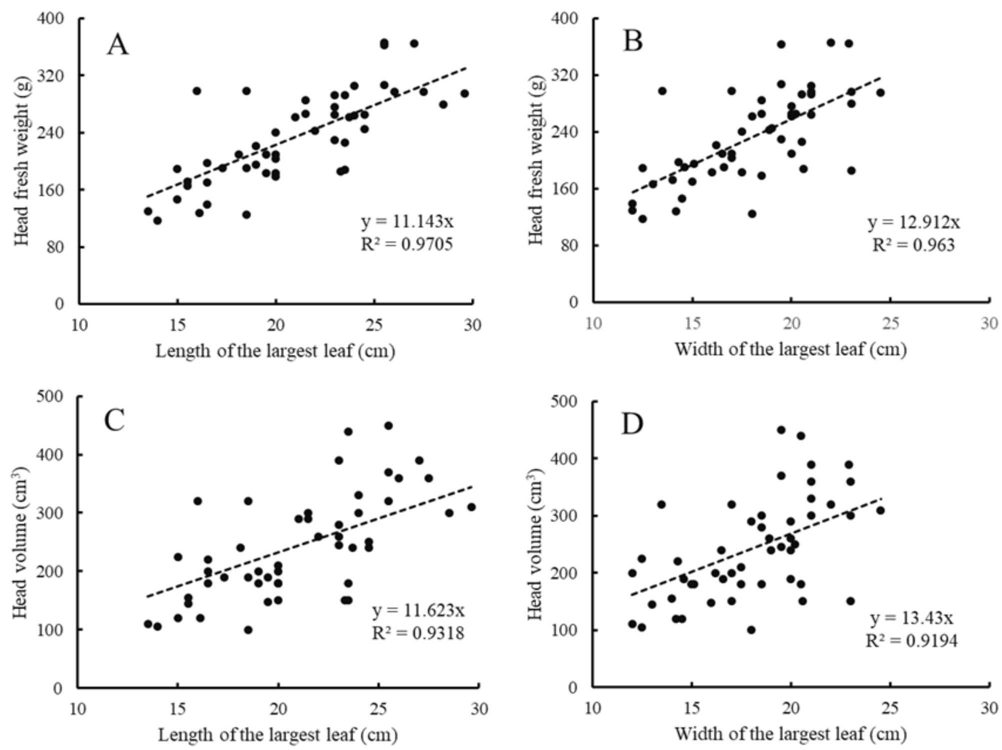

Fig. 6: Predicting head fresh weight (A and B) and volume (C and D) based on length and width of the largest leaf prior to head development at 9 weeks after sowing

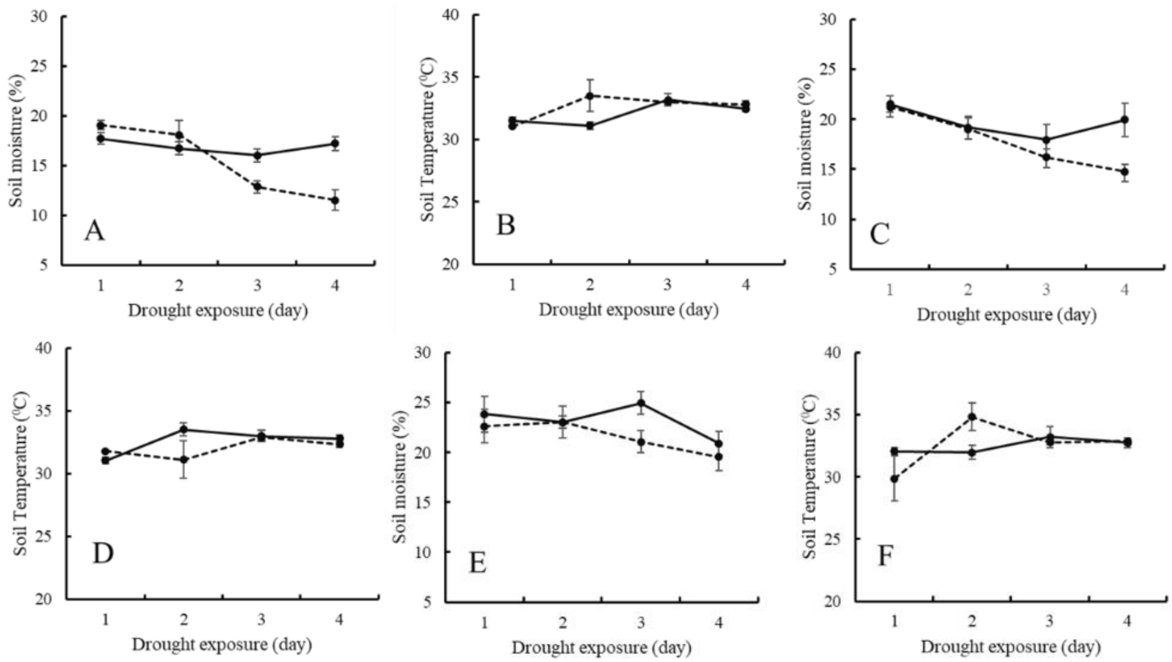

Fig. 7: Soil moisture and temperature measured during drought exposure at 7 WAS for cabbage plants transplanted at 3 WAS (A and B), 4 WAS (C and D) and 5 WAS (E and F). Broken line represents stressed plants and solid line represents control plants data

Fig. 8: Wilted leaves of tropical lowland cabbage after consecutively exposed to drought stress for 4 days

The most significant decreased in percentage of leave water content (LWC) was observed in cabbage plant transplanted at 3 WAS (Fig. 9). Decrease in LWC is associated with loss of water due to transpiration and limited water absorbed by plant roots under low soil moisture in growing substrate. Plant with large total leaf area lost more water to surrounding air and depleted more water in substrate. Cabbage transplanted at 3 WAS had higher total leaf area as indicated by higher canopy area, number of leaves and average leaf size. Less decrease in SLWC compared to decrease in percentage of LWC was associated with restriction of leaf expansion due to lack of internal hydraulic pressure under limited water content in the leaves of drought stressed plants.

Effects of early transplanting and short-term drought on the yield

Early transplanting of 3-week-old seedlings resulted in early harvest of tropical lowland cabbage, higher head yield and larger head volume; but density of the fresh head was significantly less than that transplanted a week later using 4-week-old seedlings (Fig. 10). Also, early transplanting increased dry head biomass and head water content (Table 1); however, short-term water stress did not cause long term effect on growth and yield of cabbage plant, except slight increase in head fresh weight for plant exposed to drought stress prior to head initiation and decrease in head fresh weight for plant exposed to drought during head enlargement.

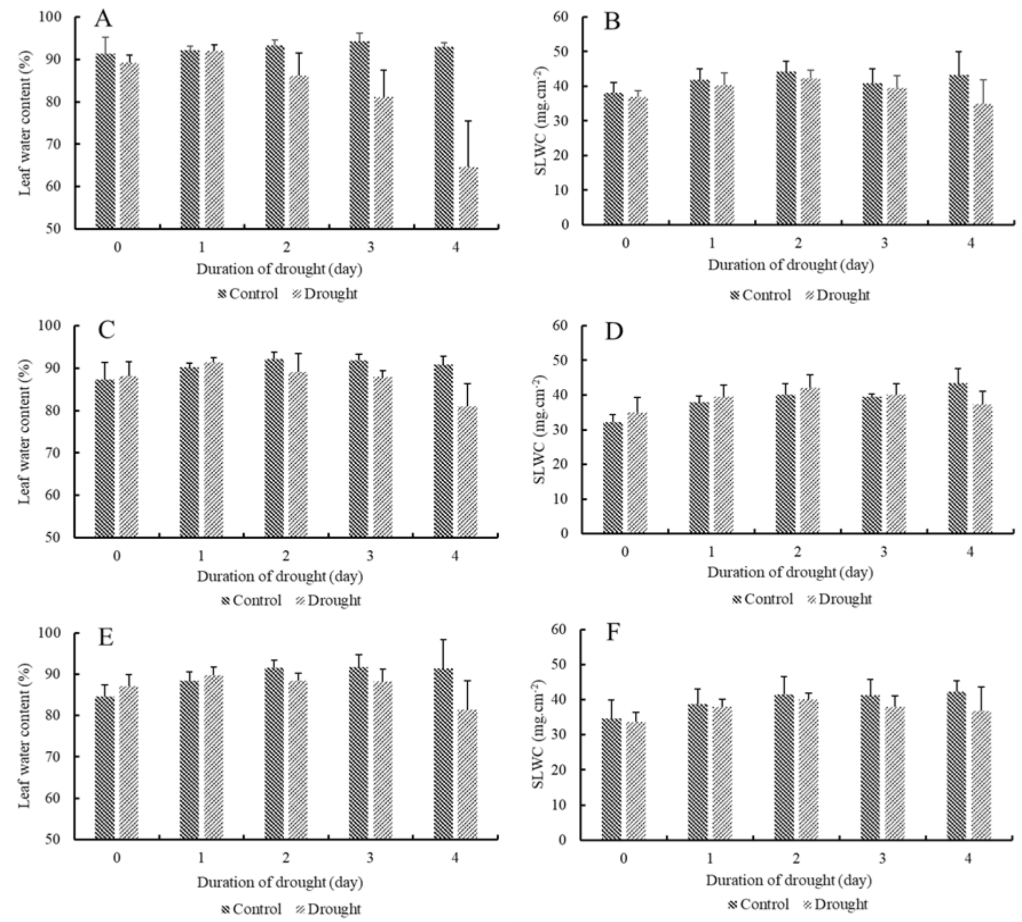

Fig. 9: Leaf water content and specific leaf water content during 4 days of gradual soil drying in tropical lowland cabbage transplanted at 3 WAS (A and B), 4 WAS (C and D), and 5 WAS (E and F)

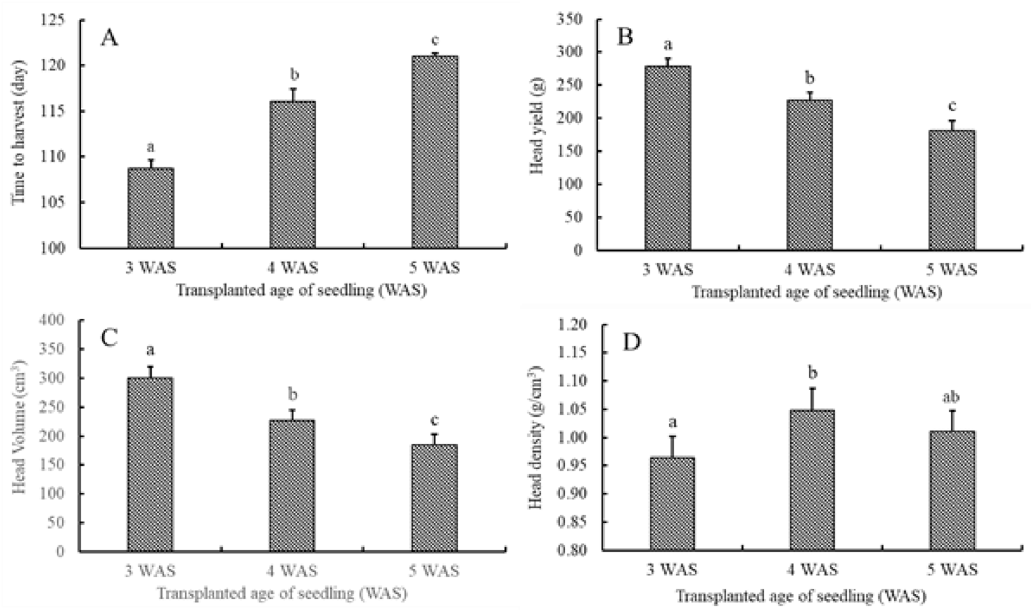

Fig. 10: Delaying transplanting caused delay time of harvest (A), decreased head yield (B), decrease and head volume (C), and highest head density in the tropical lowland cabbage transplanted at 4 WAS (D)

Table 1: Dry head biomass and head water content in lowland cabbage

Treatment	Dry head biomass (g)		Head water content (%)	
T_1 (3 WAS)	21.47	a	93.31	a
T_2 (4 WAS)	18.13	b	91.92	a
T_3 (5 WAS)	13.78	c	91.91	a
LSD 0.05	3.11		1.42	
Control	18.60	a	91.86	a
Drought at Week 9	18.80	a	92.31	a
Drought at Week 13	15.98	a	91.96	a
LSD.05	3.11		1.42	

Mean values within a column followed by the same letters are not significantly different at $P < 0.05$

Discussion

There are many reasons for farmers to prepare seedlings in nursery and then do transplanting the seedlings to the field or larger pots at a certain time. Benefits of preparing seedlings prior to transplanting are usually compared with direct seeding practice. The benefits include: (a) easier to maintain at earlier seedling growth since the practice require less space, less water, and less weed to handle; (b) able to intensively monitor seedling development and taking immediate action if unexpected things happen; (c) making possible to start growing season earlier in location with natural climatic limitation such as long inundation period in riparian wetlands using floating seedling preparation system (Ramadhani *et al.* 2018; Siaga *et al.* 2018; 2019; Jaya *et al.* 2019) or in long winter climate by preparing seedling within the greenhouse before transplanting seedling to the field; and (d) selecting uniform seedlings to be used for cultivation on field or hydroponic system.

Delaying transplanting of rice seedlings has been a popular research topic (Huang *et al.* 2019; McDonald *et al.* 2019; Lampayan *et al.* 2019); however, much less research have been focused on similar topics for vegetable crops despite transplanting is also commonly practiced. Delaying transplanting means farmers use older seedlings. Lampayan *et al.* (2015) reported that use of oldest seedlings (30-day old) consistently resulted in lower yield and found that critical seedling age for rice was around 20 days old. However, the exact critical age in rice plant varies amongst varieties and agro-climatic conditions. For instance, Brar *et al.* (2012) reported that transplanting of 30-day old seedlings gave significantly higher grain yield and water productivity over 60 days old seedlings.

Result of this study indicated that the seedlings accelerate their growth soon after being transplanted from each tiny cell in tray to much larger pot containing spacious growing substrate for roots to explore. In contrast, growth of seedlings kept in plug cell was almost completely halted; therefore, delaying transplanting extent halted growth in seedlings. Decrease in growth and yield of vegetables had been reported in onion (Khan *et al.* 2019), winter squash (Conti *et al.* 2015); however, negative effects of delaying transplanting may also associate with change of climatic condition (Kandil *et al.* 2013). Meanwhile, Shin *et al.* (2000) reported that growth of red pepper seedlings was faster if larger plug cells were used, suggesting that limited rhizosphere halted growth; or as a plant grows, it requires larger rhizosphere.

Continuous monitoring of leaf or canopy expansion rate requires non-destructive measurement (Lakitan *et al.* 2017; Shabani and Sepaskhah 2017). In leafy vegetables, total leaf area can be used as proxy for yield. Therefore, frequency of new leaf development and leaf expansion rate are valuable for developing model on predicting time to harvest. Leaf length (L), leaf width (W), and combination of the two (L x W) were very reliable predictors for leaf area. L x W is also reliable for estimating canopy area of cabbage up to 6 WAS. At 7 WAS and older, leaves of cabbage started to randomly overlay between one to another; therefore, total area of sun-lighted canopy cannot be consistently predicted based on L x W. It should be beneficial if head weight and volume can be predicted using any measurable physical characteristics in cabbage measured at 6 WAS.

Morphological characteristics during early vegetative growth prior to head initiation disclosed legitimate relation to head yield. The trends were clear that cabbage plants with larger canopy size at 5 WAS, larger leaf size at 7 WAS and longer leaf midrib at 9 WAS produce higher head fresh weight and larger head volume, but they were not characterized by higher head density. Accuracy of the prediction was much better when it was made at 9 WAS.

It was interesting to note that short-term drought exposed prior to and during heading phase significantly decreased soil moisture and leaf water content during stress exposures, also visually exhibited severe leaf wilting; yet, cabbage plants were able to recover after the short-term drought stress and the yield was not significantly affected. Yin and Bauerle (2017) argued that plant hydraulic pressure, leaf anatomy and physiology affect plant propensity towards recovery, and reflect evolutionary consequences of plant adaptation to their habitat. Physiologically, Wang *et al.* (2019) explained that drought-resistant cultivar had a smaller photosynthetic affected area, longer catalase enzyme activity duration, and lower H_2O_2 accumulation. However, in this case, cabbage has a large total leaf area. As a response to this dispute, Hlavacova *et al.* (2018) provided relevant argument that response of photosynthetic parameters to short-term (3–7 days) drought were more pronounced than yield parameters. In this study, short-term drought stress did not significantly affect time to harvest, economic yield, biomass, and water content at harvest. Short-term acute or moderate drought stress for 4 days increased in content of functional compounds (flavonoids, carotenoids, chlorophylls) and total antioxidant activity at harvest in lettuce (Paim *et al.* 2020). Niu *et al.* (2018) also reported that moderate drought stress was beneficial to root growth and yield in cotton plant. Interaction between abscisic acid and gibberellic acid signals might play an important role in root growth compensatory effects.

Conclusion

In conclusion, seedlings of tropical lowland cabbage should be transplanted at 3 WAS for earlier harvest and higher head yield. Head yield can be predicted as earlier as 5 WAS using canopy area as predictor; however, more accurate prediction could be achieved at 9 WAS using length of leaf midrib as predictor. Short-term (4 days) gradual drought exposure did not significantly affect head yield and biomass of the cabbage plant used in this study. It is recommended that farmers should transplant the cabbage seedlings at age of three weeks after seed sowing. Farmers should not excessively water their cabbage plants. Watering can be applied at every other days or every three days for reducing water use in cabbage cultivation.

Acknowledgements

We deeply appreciate the kind attention by the editor of this journal; also, for comments and suggestion by the anonymous reviewers of our manuscript. This research was funded by the Applied Research Program, Ministry of Education, Culture, Research and Technology, Indonesia. Grant Number 299/SP2H/LT/DRPM/2021.

Author Contributions

BL created and designed the research; did specific statistical analysis; wrote the fist and submitted version of the manuscript; acted as corresponding author. KK supervised data collection and analysis; edited and enriched the manuscript. NP performed all field works; collected raw data and conducted basic statistical analysis.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Data Availability

All the related Ddata is available and reported in the manuscript. will be available as requested.

Ethics Approval

The authors declare that the research was in accordance with all ethical standards.

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