Response of wheat (*Triticum aestivum*) growth and yield to the different water shorthage periods

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**Abstract.** Wheat plants can grow and produce well on the island of Lombok, ranging from highlands to lowlands around 400 m above sea level, and have opportunities for further development. This adaptation effort needs to be followed by development of cultivation technology, including proper irrigation. Irrigation is a fundamental factor in achieving maximum yields in a crop land. Wheat crop does not require a large amount of irrigation as rice plants, but it is not yet known which growth periods are critical to the water requirements for wheat plants grown on Lombok Island. This study aims to determine the effect of water stress at different growth phases of wheat on the growth and yield of wheat plants. This research was conducted using the Experimental Method in a greenhouse, with 9 water stress treatments at different phases. The treatment of water stress at different period of plant development does not show a different effect on plant growth and development. However, it significantly reduces yield and yield components. The critical period of water requirements for wheat plants occurs when the plants reach the generative phase; plants experience pressure in grain production, especially when water stress occurs in the phases of heading and flowering (anthesis). Stress in the booting and milk-development phases also experiences reduction on grain production, even at the lower levels.

1. Introduction

Indonesia needs to make efforts to cultivate and produce its own wheat to reduce wheat imports. Efforts to adapt wheat in tropical Indonesia must be actively carried out. Research carried out in 2010 to 2016 shows that introduced wheat plants from Australia and National varieties can grow and produce well on the island of Lombok, and have opportunities for further development [1].

Lombok Island, which is located at 8° South 116° East, is a potential area for wheat crop development considering that most of these areas are rain-fed, while wheat can adapt well to dry land that cannot be well-cultivated by rice. The simulation conducted by Gusmayanti et al [2] and Handoko [3] show that wheat is possible to be produced on Lombok Island with a potential yield of between 1.5-3.0 t/ha. Our research from 2010 to 2013 showed that yield reached 3 t/ha in the highlands [1,4].

Wheat can grow well if the availability of water is maintained during its growth. Besides that, the accuracy of water supply suitable with the growth phase of wheat plants also determines the level of crop production. Plant growth stages also affect the ability of plants to adapt to water availability because water requirements can be different in different wheat growing stage [5,6]. In general, the water demand of wheat plants when entering the generative phase increases. The status of water in plants is important
to know so that farmers can provide the amount of water based on their needs. By knowing the amount of water needed, an appropriate irrigation application can be planned and determined.

The availability of water in the right amount determines the productivity of a plant. Wheat plants need water around 450-650 mm per planting season [7], comparable to the water needs of sorghum plants (400-500 mm) [8,9] and corn (500 -600 mm) [7]. The effect of too little or too much irrigation can reduce wheat productivity [10-12]. Wheat plants that experience mild water shortages alone can cause a decrease in photosynthesis, decreased stomatal conductance (Gs) and evapotranspiration (ET). If stress continues then it can cause intercellular CO2 concentrations (Ci) to increase which shows a decrease in photosynthesis from the non-stomata effect [11]. Conversely, if the plant experiences excess water it can cause photosynthesis decline and photosynthetic organ damage, also decrease evapotranspiration and water use efficiency (WUE) [12]. Both, lack or excess water can reduce crop production.

Wheat does not require a large amount of water in its growth, unlike rice, so wheat can also be cultivated on lands with a limited source of water. In some regions/countries with limited water, such as in Australia or India, wheat is only irrigated twice during the growing season, during the initial vegetative phase and during anthesis. In cases like this, stress often occurs after the anthesis or during panicle/seed development. If more water is available, irrigation is done in the final vegetative phase, before heading. And so on if the water supply is more adequate, irrigation will be carried out after the anthesis or panicle development phase.

This study aims to determine the phases of growth that are most sensitive to water stress for wheat plants and evaluate the effect of water stress on the growth and yield of wheat plants. The results of this study can determine the right period/timing for watering so that it can be done as efficiently as possible for optimal grain yield.

2. Materials and methods
An experiment was carried out in a greenhouse, using a Completely Randomized Design. Water stress treatment is given in 8 different periods of wheat crop growth based on Zadoks’ Scale [13]. The wheat variety used in this study is the national variety, Nias. All treatments were repeated 4 times so that there were 36 treatment units.

| Table 1. Treatment schema. |
|---------------------------|
| Treatment | Cereals development period [13] |
|            | I | II | III | IV | V | VI | VII | VIII |
| Seedling growth | Stress | √ | √ | √ | √ | √ | √ | √ |
| Tillering | stress | √ | √ | √ | √ | √ | √ | √ |
| Stem elongation | √ | √ | stress | √ | √ | √ | √ | √ |
| Booting | √ | √ | √ | stress | √ | √ | √ | √ |
| Heading | √ | √ | √ | √ | Stress | √ | √ | √ |
| Flowering | √ | √ | √ | √ | stress | √ | √ | √ |
| (Anthesis) | √ | √ | √ | √ | √ | √ | √ | √ |
| Milk dev. | √ | √ | √ | √ | √ | √ | √ | √ |
| Dough dev. | √ | √ | √ | √ | √ | √ | √ | √ |

Notes:

stress : Water stress applied to plant on the development periods for 10 days
√ : plants were watered, no stress applied

In this experiment, Nias was treated with water stress (no irrigation applied for 10 days), when reaching the following phases; seedling growth stage (Zadoks Scale/ZS 11), tillering (ZS 21), stem elongation
(ZS 31), booting (ZS 45), heading (ZS 55), anthesis (ZS 65), milk development (ZS 71). In control, water was given in all watering schedule (Table 1). Seed planting is carried out in polybags, 4 seeds are planted in each poly bag. The poly bag has been prepared beforehand to be filled with soil and given water to field capacity. Water content of this field capacity is the standard for water added for each treatment. Each polybag was kept on field capacity except for the treatment plants, will not be watered for 10 days in treatment period.

Plants were fertilized with Urea and NPK, weed control is done manually, while pest and disease control is not carried out because there are no cases of pests and diseases. Harvesting is done around 97 days after planting when the plants ripe.

Observations were made on plant height, growth phase, dry matter weight, number of stems, as well as yield and yield components, namely: number of head (panicles), number of spikelet, number of spikelet/head, number of seeds, number of seeds/spikelet, thousand grain weight and total grain weight.

Data were analyzed by analysis of variance at 5% significance level using the GenStat Statistical Program. Significantly different treatments were tested further with the Least Significant Difference test (lsd) at the 5% level.

3. Results and discussion

Growth and development of wheat plants with water stress treatment at different periods did not show any difference, both in plant height and plant development phases. This can be caused by a short stress treatment.

Wheat plants appear to show a low height increases at the beginning of growth until around the age of 5 weeks, after which they experience rapid growth height between 5 to 8 weeks. After that the growth of plant height is low again almost no visible increase in plant height after 9 weeks of age, after the plants reach the generative growth phase. This growth curve is known as the sigmoid growth type, which resembles the letter 'S'. Plant height until the end of the observation reaches about 60-70 cm (Figure 1).

In general, there is no significant difference in height and development phase due to the water stress treatment at different phases. The difference in water stress treatment significantly affect yield and yield components. The treatment of water stress in generative phases yields lower than the treatment of water stress in the vegetative phases, but in the final generative phase (stress in the period of milk ripe phase) does not experience high production pressure (Table 2).

The effect of water shortages in the initial growth phase on grain yields and wheat biomass which was widely reported did not occur in this experiment. Shortage of water in the initial phase can affect
the accumulation of wheat biomass due to the low or decreasing leaf area index and the efficient use of solar radiation [14]. A report stated that interception of solar radiation correlates with the accumulation of dry weight of wheat plants [15]. In this experiment, water stress treatment in the initial phase had no effect because of the short duration of stress treatment and the availability of water from irrigation before the treatment period.

Dry matter weight (DMWt.) begins to decrease during the water stress treatment at booting phase, and the lowest DMWt is found when water stress occurred at heading and flowering (anthesis) phases. Genetic and environmental factors play a major role in the process of tiller formation in the early vegetative and late vegetative periods [16]. Water stress in the milk development phase also gives a lower dry matter than water stress treatment during the vegetative phase, although water stress treatment at this phase gives a higher dry matter than water stress in booting, heading and flowering phases.

Table 2. Yield and yield components of Nias treated with water stress during different growth stages at Perian East Lombok in 2019.

| Water stress treatment       | Tiller number | Dry Matter Weight | Head number | Spikelet / Head | Seed number | Seed / Spikelet | Seed weight (g) | TGW (g) |
|-----------------------------|---------------|------------------|-------------|-----------------|-------------|----------------|-----------------|---------|
| Control                     | 18.7          | 32.46            | 16.0        | 14.4            | 434         | 1.9            | 14.70           | 33.8    |
| Seedlings growth (S1)       | 19.7          | 32.60            | 16.0        | 15.6            | 401         | 1.6            | 14.43           | 35.9    |
| Tillering (S2)              | 18.0          | 31.77            | 15.0        | 13.1            | 393         | 2.0            | 13.89           | 35.2    |
| Stem elongation (S3)        | 23.0          | 34.93            | 19.0        | 13.2            | 432         | 1.7            | 15.06           | 35.1    |
| Booting (S4)                | 17.0          | 17.11            | 11.3        | 10.8            | 192         | 1.6            | 5.36            | 27.5    |
| Heading (S5)                | 10.7          | 9.14             | 7.3         | 9.6             | 108         | 1.4            | 1.86            | 18.5    |
| Anthesis (S6)               | 13.0          | 12.60            | 5.3         | 12.8            | 125         | 2.0            | 2.02            | 18.4    |
| Milk development (S7)       | 19.7          | 22.58            | 13.7        | 12.2            | 309         | 1.9            | 7.34            | 23.8    |
| Dough development (S8)      | 18.7          | 27.31            | 15.7        | 13.3            | 380         | 2.1            | 10.49           | 27.4    |
| Grand Mean                  | 17.6          | 24.50            | 13.0        | 12.8            | 308         | 1.8            | 9.46            | 28.4    |
| l.s.d.                      | 6.11          | 5.86             | 4.66        | 2.78            | 110.4       | _              | 3.34            | 5.9     |

The total number of productive head in water stress treatment during the vegetative phases such as the seedling growth, tillering and stem elongation phases did not differ from controls. This number decreased significantly when the water stress occurs in the generative phases starting at booting, heading, and flowering phases (Table 2).

The number of spikelet/head and number of seeds decreases significantly if stress occurs in generative phases and the lowest number are found in plants experiencing stress during booting and heading. Water stress that occurs during the heading and flowering phases also reduces the total weight of seeds harvested and the weight of 100 grains.

The treatment of water stress during the heading and anthesis (flowering) periods gave the lowest yield, 1.86 g/pot and 2.02 g/pot, respectively. In this experiment, the decrease in grain yield caused by water stress that occurs in heading and flowering reached 86% of the grain yield under control. The low yields in these periods are seen to be caused by the low number of tillers formed, the small dry matter
weight, the number of head and productive head produced. The accuracy of the availability of water in the growth stage affects the production of wheat [5,6]. Optimal yield will be achieved if the plants supplied by enough water in the phases of heading, flowering, and grain filling.

Grain yield is also affected by the length of time and intensity of the water deficit and the growth phase in which water stress occurs. Wheat plants are more tolerant of water shortages at vegetative and the maturing phase compared to other phases. Heading and flowering phases are the most critical phases and water shortages at this phase will result in the highest yield losses, reaching 80% in this experiment, however on initial growth i.e. seedling formation, tillering and stem elongation phases, did not show any significant difference in yield and yield components, maybe due to availability of initial water on the early growth.

Lack of water in the flowering phase causes the formation of pollen disturbed thereby reducing the number of head per plant, head length, and number of seeds per head [17]. Drought also interferes with root development and even causes plants to die. Besides the lack of water, hot weather conditions accompanied by dry winds make the seeds become tangled so that the quality is low.

Shortage of water availability in the seed filling phase causes accelerated aging of plant leaves and the seed filling period becomes 10 days faster. This has an impact on accelerating the rate of seed filling and increasing mobilization of carbohydrate reserves which results in a decrease in yield [18]. In this experiment, lack of water in the seed filling phase reduced seed yield by 29-50%. The accuracy of the availability of water in the growth stage affects the production of wheat.

4. Conclusion

The treatment of water stress in all phases of plant development has no different effect on plant growth and development. Water stress in the vegetative growth phase does not have a significant effect on yield and yield components of plants. Plants experience the greatest pressure in seed production, especially when water stress occurs in the heading and flowering phases, while water stress in the booting phase and the seed maturing phases also results in decreased seed production, at lower levels.

References

[1] Zubaidi A, Ma’shum M, Gill G and McDonald G K 2018 Wheat (Triticum aestivum) adaptation to Lombok Island Indonesia AGRIVITA Journal of Agricultural Science 40 3 556–566
[2] Gusmayanti E, Pertiwi S, Handoko I, Risdiyanto I and Machida T 2006 Determining potential wheat growing areas in Indonesia by using the spatial compromise programming technique Agric. Inf. Res. 15 373-379
[3] Handoko I and Gandum G 2000 Penelitian pengembangan gandum di Indonesia (Jakarta: SEAMEO BIOTROP)
[4] Zubaidi A, Yakop U M and Anugrahwati D R 2018 Pertumbuhan dan hasil gandum pada berbagai kerapatan populasi dan dosis pemupukan urea J. Agron. Indonesia 46 3 262-268
[5] Akram M 2011 Growth and yield components of wheat under water stress of different growth stages Bangladesh J. Agril. Res. 36 3 455-468
[6] Wang J, Xu C, Gao S and Wang P 2013 Effect of Water Amounts Applied with Drip Irrigation on Water Consumption Characteristics and yield of Spring Wheat in Xinjiang Advance Journal of Food Science and Technology 5 9 1180-1185
[7] Aqil M, Yasin M and Talanca A H 2016 Kesesuaian Lahan dan Pengelolaan Air pada Tanaman Gandum In Praptana H, Hermanto (Eds.) Gandum, Peluang pengembanannya di Indonesia (IAARD Press)
[8] Steduto P, Hsiao T C, Fereres E and Raes D 2012 Crop yield response to water (Rome: Food and Agriculture Organization of the United Nations)
[9] Aqil M and Bunyamin Z 2016 Pengelolaan air tanaman sorghum. In Sorgum: Inovasi Teknologi dan Pengembangan (Jakarta: Badan Penelitian Dan Pengembangan Pertanian)
[10] Kilic H and Yagbasanlar T 2010 The Effect of Drought Stress on Grain Yield, Yield Components and some Quality Traits of Durum Wheat (Triticum turgidum ssp. durum) Cultivars Notulae
Bot. Hort. Agrobot. 38 164-170

[11] Liu E K, Mei X R, Yan C R, Gong D Z and Zhang Y Q 2016 Effects of water stress on photosynthetic characteristics, drymatter translocation and WUE in two winter wheat genotypes Agricultural Water Management 167 75-85

[12] Shao G C, Lan J J, Yu S E, Niu N, Guo R Q and She D L 2013 Photosynthesis and growth of winter wheat in response to waterlogging at different growth stages Photosynthetica 51 429–437

[13] Zadoks J C, Chang C T and Konzak C F 1974 A decimal code for the growth stages of cereals Weed Res. 14 415-421

[14] Jamieson P D, Semenov M A, Broking I R and Francis G S 1998 Sirius: A mechanistic model of wheat response to environmental variation European J Agron. 8 161-179

[15] Kiniry J R, Jones C A, O’Toole J C, Blancet R, Cabelguena M and Spanel D A 1989 Radiation-use efficiency in biomass accumulation prior to grain-filling for five grain-crop species Field Crops Res 20 51-64

[16] Longnecker N, Kirby E J M and Robson A 1993 Leaf emergence, tiller growth, and apical development of nitrogen deficient spring wheat Crop Sci. 33 154-160

[17] Ottman M, Kimball B A, White J W and Wall G W 2012 Wheat Growth Response to Increased Temperature from Varied Planting Dates and Supplemental Infrared Heating Agron J. 104 7-16

[18] Yang J, Zhang J, Huang Z, Zhu Q and Wang L 2000 Remobilization of carbon reserves is improved by controlled soil-drying during grain filling of wheat Crop Sci. 40 1645–1655