Proceedia 2021

The 5th SATREPS Conference
Bogor Nov 17, 2020
"The Project for Producing Biomass Energy and Material through Revegetation of Alang-alang (*Imperata cylindrica*) Fields"

WATER STRESS AND WATER REQUIREMENT OF SORGHUM: CASE STUDY OF DRY AREAS IN EAST NUSA TENGGARA PROVINCE

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Abstract

East Nusa Tenggara Province, known as a dry area in Indonesia with sub optimal soil and uncertain climate. Although sorghum (*Sorghum bicolor*) is known to be suitable plant in this area, the sub optimal soil and the long period of dry season often become constraint for the cultivation. Sorghums still need enough water during their period of life. Research conducted in the green house and in the field in Cibinong indicated that water deficit will affect the physiological characteristics. To develop sorghums suitable for cultivation in the East Nusa Tenggara Province, simulation of water requirement of two types of sorghums with sub optimum soil was conducted. The simulation of crop factor and soil factor resulted that grain sorghum with stages and total life period of 130 days (vegetative, reproductive, maturity and harvesting stage) needs a total of 371 mm of water, and number to irrigate was 5 multiplicated by 58 mm. While sweet sorghum with stages and total life period of 140 days needs a total of 479 mm water, and number to irrigate 12 multiplicated by 40 mm. This simulation was very important in order to develop sorghums that can adapt to lacking of water environment by applying some water use efficiency technique.

Keywords: dry area, East Nusa Tenggara Province, simulation, sorghum, water requirement

1. Introduction

Sorghum (*Sorghum bicolor* [L.] Moench) is a crop indigenous to Africa that has been domesticated in Ethiopia about 5000 years ago. It is now widely cultivated in dry areas of Africa, Asia, the Americas, Europe and Australia between latitudes of up to 50 °N in North America and Russia and 40 °S in Argentine. Sweet sorghum is a variant closely related to grain sorghum; it differs mainly that its stalks are taller and juicier with higher sugar content than the grain sorghum type. Sorghum is the fifth most important cereal in the world after wheat, rice, maize and barley. In Africa it ranks second after maize in terms of production. Sorghum is well adapted to tropical climates with several traits making it a drought-tolerant crop that survives under adverse climatic conditions, and thus is often relegated to poor soils and low-input management. It is extensively grown under rainfed conditions for grain and forage production. High production may be achieved when sufficient water and nutrients are applied especially at critical stages of crop growth [1], [2].

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Published in May 2021, *http://publikasikr.lipi.go.id/index.php/satreps*

The word "sorghum" typically refers to cultivated sorghum (*Sorghum bicolor* [L.] Moench subsp. *bicolor*), a member of the grass family Poaceae, tribe Andropogoneae, and sub tribe Sorghinae that is grown for its grain (grain sorghum), its sugary sap (sweet sorghum) or as a forage (forage sorghum) [3], [4], sorghum crops grown for the fibers in the stems, which are used to make brooms and brushes (broomcorn) [3].

Sorghum is a widely adaptable species that is cultivated as an annual cereal and forage crop in tropical, subtropical and temperate regions of the world. Sorghum grain is a staple human food in Africa and Asia, but is grown almost solely as a livestock feed in the western hemisphere [5].

East Nusa Tenggara Province, known as a dry area in Indonesia with sub optimal soil and uncertain climate. Monthly evapotranspiration rate is around 150 to 200 mm. Although sorghum (*Sorghum bicolor*) is known to be suitable for cultivation in this area, the sub optimal soil and the long period of dry season often become constraint for the cultivation.

Sorghum is considered to be drought resistant, especially in comparison to maize. A part of the perceived resistance may be because sorghum cultivars grow in water-limited areas, are the short-season type, thus their water requirement is less than maize, a crop that generally has a longer life cycle [1]. Although grain sorghum tolerates and avoids drought more than many other cereal crops, but the drought response of sorghum does not occur without a yield loss. Water stress at the vegetative stage alone can reduce yield more than 36%, and water stress at the reproductive stage can reduce yield more than 55%. Eighty percent of sorghum production in the world is under dryland conditions [6].

Sorghums require sufficient water during their period of life. If they are not irrigated enough water at their development stage, they will experience water stress. The water stress will decrease photosynthetic rate, cells development, and yield productivity [1], [7]. Knowledge on crop water requirement is very important in agriculture for designing and managing irrigation and drainage systems [8]. The problem is how much water and when water should be given to irrigate sorghum?

To identify sorghum water requirement, it can be calculated by understanding the reference crop evapotranspiration (Eto) and crop evapotranspiration (ETcrops) [9]. This method was developed by considering the role of crop factors to affect evapotranspiration, crop evapotranspiration under standard and non-standard included drought condition [10]. To estimate crop water use, we need to consider the crop, soil and climate factors [11]. Research to understand the optimum water irrigation according to sorghum requirement is very important particularly in the dry area of Indonesia. The objective of research was to simulate water requirement of two type of sorghums with sub optimum soil and dry climate.

2. Methods

a. Sorghum cultivation and leaf water potential measurement

Sorghum seeds were cultivated in soil medium containing top soil, organic fertilizer and sand (50:20:30) in four 1x1.2x1 m^3 containers. Seeds were sown in soil media pre-treated with tap water under field capacity. Leaf water potential was observed one month after planting by using WP 4 Dew Point. Plant growth performances, including plant height and leaf width were observed.

b. Physiological research

Research to understand Physiological characteristics of sorghums under water deficit was conducted in the green house and in the field in CSC LIPI Cibinong. Licor-6800 Portable Photosynthesis System (LI-COR, USA) was used to observe gas exchange including photosynthetic rate (A), transpiration rate (E), and stomatal conductance to water vapour (gsww). It was operated under the photosynthetic photon flux density (PPFD) or Qinleaf from the open sunlight as the light source. The measurements were performed between 09.30 to 10.30 AM. The settings of the for the reading were as follows: flow rate: 500 µmol s^{-1}, RH: 50 %, CO_2 reference: 400-500 µmol^{-1}, fan speed: 8000 rpm, control temperature/TxCh: 27-28^{0}C, leaf constant: 3 cm x 3 cm, and PPFD from natural sun light [12].

Research was conducted in the Green House of the Research Center for Biotechnology, the Indonesian Institute of Sciences (LIPI). The experiment was designed by using randomized complete block design with 20 sorghum genotypes (consisted of grain and sweet sorghums) and 2 water treatments (control and water stress), with 2 replications. The control plants were irrigated under field capacity, while the water stress treated plants were sown under field capacity followed by drought treatment without watering for one month. Sorghum seeds were cultivated in soil medium containing top soil, organic fertilizer and sand [13].

c. Sorghum development stage

The rate of leaf appearance in sorghum is closely related to thermal time. When temperature is ideal, it takes about 2 days for each new leaf to emerge. For a cultivar with 18 leaves, in India a typical phenology and growth stages of 0 to 9 (Vanderlip and Reeves, 1972) are as follows: emergence (0); 3-leaf stage (6 days after emergence); 5-leaf stage (16 days after emergence); panicle initiation (32 days after emergence, approximately 9 leaf stage); flag leaf appearance (50 days after emergence, tip of final leaf visible in the whorl); boot stage (head enlarges in flag leaf sheath, 60 days after emergence); 50 percent flowering (68 days after emergence, half of the plants complete pollination, from the tip downwards); soft dough stage (80 days after emergence, squeezing kernel between fingers results Sorghum 147 in little or no milk); hard dough stage (96 days after emergence when seed cannot be compressed between fingers); and physiological maturity (106 days after emergence, black layer (spot) appearance on the hilum at the base of the seed). The sorghum development stage (vegetative, reproductive, maturity, and late season) can be illustrated and summarized in the Figure 1 [1], [2].

Vegetative	Reproductive	Maturity	Late season
Day-1 : Emergency 6 DAE : 3 leaves 16 DAE: 5 leaves 32 DAE: 9 Leaves 50 DAE: 18 leaves	60 DAE: 50 % flowering	80 DAE: soft dough stage 96 DAE: seed can not be compressed by finger	106 DAE: black layer spot 110 DAE : harvesting

Source: FAO, No. 66, 2012; Widiyono, W. 2020

Figure 1. Typical development stage of sorghums genotype

Phenological research was conducted to know the starting of flowering of 30 sorghum accession resulted that sorghums first flowering taken place at 7 weeks, 8 weeks, 9 weeks, 10 weeks and 11 weeks after planting [14].

d. Simulation steps

Water requirement simulation used two types of sorghums (grain sorghum and sweet sorghum), with sub optimal soil, and dry climate. This experiment consisted of (1) the relationship between crop and soil (crop factors and soil factors); (2) the relationship between crop and climate. The relationship between crop and soil was used to understand Net Irrigation Depth or how much water deficit threshold. It used parameters of the Maximum Root depth, Depletion fraction, Length of Development Stages, Crop Coefficient, Total soil available water/TAW, and Readily soil available water/RAW = p x TAW; while the relationship between crop and climate was analyzed to understand daily and total water deficit. It used parameters of potential evapotranspiration (Eto = Kp * Evo), Crop Coefficient (Kc), ET crop/water use for Sorghum, Etc = ETo * Kc, Effective rainfall = rainfall -5 mm, Irrigation application have to do when we face water deficit. The simulation parameters and their coefficient value were reported in Table 1.

Table 1. Simulation parameters to simulate sorghum water requirement

1) Relation Crop and soil	Crop Factors				Soil Factors		
Sorghum types	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Maximum root depth	Depletion fraction	Length of development stages (days)	Crops coefficient Total soil available water	Total soil available water	Readily soil available water	Net irrigation depth
Grain sorghum	1.5	0.55	20/5/40/30 = 130	0.55/1.05/ 1.05/0.55	106	58.3	87.45
Sweet sorghum	0.75	0.50	20/35/45/30 =140	1.05/1.2/1. 2/1.05	106	53	39.75

2) Relation crop and climate

(1)	(2)	(3)	(4)	(5)	(6)
Eto = Kp*Evo. Kp = 0.85	Crop coefficient (Kc) = 20/35/40/30	ET crop for grain sorghum, Etc = ETO*Kc	Effective rainfall = rainfall - 5mm	Irrigation application have to do, if water deficit up to 87 0r 40 mm	Daily soil water deficit

3. Results and Discussion

a. Photosynthetic rate and leaf water potential to indicate water stress

Photosynthetic rate and leaf water potential can be used to understand crop response to water and light intensity. Sorghums photosynthetic rate in the greenhouse was very influenced by light intensity absorbed of sorghums leafQ (Qleaf in). Photosynthetic rate in the morning higher than in the afternoon, and row sorghum that received more light intensity tend to have high photosynthetic rate. Even, sorghums photosynthetic rate in the field higher than in the greenhouse [12].

Understanding drought tolerance status in sorghum (*Sorghum bicolor*) is very important for the development of sorghum varieties suitable for sub-optimal, drought prone areas in Indonesia. We estimated drought tolerance status of 20 Indonesian sorghum genotypes (consisted of grain and sweet sorghums) by observing their leaf water potential under glasshouse condition.

Leaf water potential observation of the 20 sorghum genotypes showed that: There were 2 sorghums genotypes (KLR and KS) showed leaf water potential of -2.43 Mpa and - 2.455 Mpa, respectively, which were categorized as tolerance to water stress. Four sorghum genotypes (Buleleng Empok, UPCA, Kawali and WHP) with leaf water potentials of -3.7275 MPa, -3.7650, -3.7700 and - 3.7950 Mpa, respectively, were classified to be very sensitive to drought stress. The rest of the sorghum genotypes were classified as medium tolerance with leaf water potential between - 2.5200 Mpa and 3.6550 Mpa. Although it is preliminary results and needs to be combined with field experimental data, the results obtained was an important step in determining sorghum genotypes which was best suited to be cultivated in drought prone areas and also to identify sorghum genotypes suitable to be used as drought tolerant trait donor [13].

b. Water requirement simulation

Sorghum production is depended on water supply. Each plant has specific water requirement, depend on variety and ecological site (soil and climate characteristics). According to Crop factors (maximum root depth, length of development stage and crops coefficient); soil factors (total soil available water, readily soil available water, and net irrigation depth); and Climate factors (depletion fraction), the simulation results show:

For Grain Sorghum with 1.5 maximum root depth, 0.55 depletion factor, length of development stages 130 days; Soil factors with 106 Total soil available water. The total water requirement of the plant since germination until harvesting stage is 372 mm (or 371 liter) per m^2. It needs to irrigate 5 times with volume around 58 mm each (black diagram in Figure 2, and Table 2).

For Sweet Sorghum with 0.75 maximum root depth, 0.5 depletion factor, length of development stages 140 days; Soil factors with 106 Total soil available water. The total water requirement of the plant since germination until harvesting stage is 479 mm (or 479 liter) per m^2. It needs to irrigate 12 times with volume around 40 mm each (red diagram in Figure 2, and Table 2).

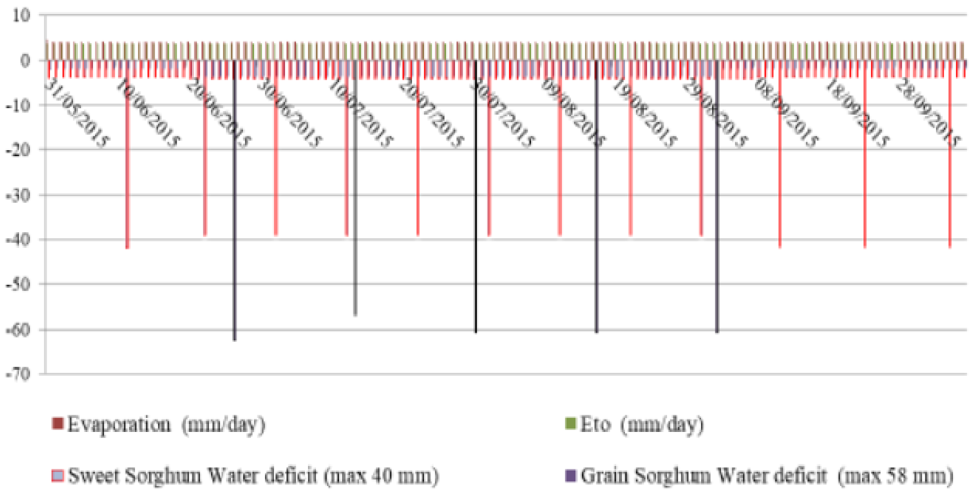

Figure 2. Simulation model of grain and sweet sorghum, with sub optimum soil and climate parameters in the dry area

Table 2. Water requirement simulation model of sorghum in the dry area (with no rainfall)

Development stages and water needs	Grain sorghum	Sweet sorghum
Stage and total period (days)	20/35/40/30 = 130	20/35/45/30 = 140
Total water needs (mm)	371	479
Number to irrigate	5 multiplicated by 58 mm	12 multiplicated by 40 mm

Our simulation was accordance with the previous research that mentioned the consumptive water use (according to evapotranspiration rate) of 110 to 130-day sorghum crops range between 450 and 750 mm, depending on evaporative demand [2]. While the consumptive water use during their life for grain sorghum was 584 mm less than corn 635 mm, and rice 1067 mm [15].

Though this simulation was good enough; however, to implement this simulation in the field need further validation process using some parameters, such as: for root depth, the data can be obtained from Sorghum cultivated in the big container; for evapotranspiration, the data can be obtained from the automatic weather station; for the length of stage, the data can be observed since germination to vegetative, reproductive, and harvesting of sorghum; for crops coefficient, the data can be obtained from further research or refer to FAO; and for the total soil available water, the data can be obtained from soil physical analysis. It was also reported [6] that research on development of crop coefficient (Kc) can also enhance crop water requirement estimates at specific crop growth stages.

4. Conclusion

The simulation of crop factor and soil factor resulted that grain sorghum with stages and total life period of 130 days (vegetative, reproductive, maturity and harvesting stage) needs a total of 371 mm of water, and number to irrigate was 5 multiplicated by 58 mm. While sweet sorghum with stages and total life period of 140 days needs a total of 479 mm water, and number to irrigate 12 multiplicated by 40 mm. This simulation was very important in order to develop sorghums based on some water use efficiency technique, such as drip watering system, sprinkler irrigation, man-made water reservoir ('embung') management. However, this simulation has weakness such as the adoption of some coefficients using reference data from FAO. It is very important in the future to simulate data using coefficient from actual field research. However, in this study it cannot be implemented mainly due to equipment and time limitations.

5. Acknowledgements

This research was supported by the JICA-JST SATREPS Project: The Project for Producing Biomass Energy and Material through the Revegetation of Alang-alang (*Imperata cylindrica*) Field, the Indonesian Institute of Sciences (LIPI).

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