Optimal irrigation at various soil types for soybean production

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Abstract. Water distribution officials at the secondary level mostly have not considered type of soil to distribute water irrigation for soybean cultivation. This study aimed to determine the optimal irrigation for soybean production at various soil types in Lombok. The study was conducted in 3 texture soil types of sandy loam, loam and clay. Each soil type was applied four treatments of irrigation water: 1 time (15 days after sowing, DAS); 2 times (15 and 45 DAS); 3 times (15, 30 and 45 DAS) and 4 times (15, 30, 45 and 60 DAS) and arranged in a completely randomized block design and repeated five times. The results showed that the highest soybean yield was obtained 4 times irrigation in sandy loam soil. In loam soil type, the highest yield of soybean was obtained at 4 times although this was not significantly different with 3 times irrigation. In clay soil type, the highest soybean yield was obtained at 4 times irrigation treatment, but this was almost a similar yield with 3 times irrigation treatments. The study suggests that schedule water delivery for soybean cultivation is recommended to increase soybean production in irrigated land.

1. Introduction

Soybean (Glycine max L. Merrill) is an important crop that is usually planted after consecutive seasons of irrigated rice in the tropical lowland rice-based cropping systems. The field is allowed to dry after the ponded rice crop that enables the planting of legume crops during the dry season. Rice is grown in anaerobic conditions for most of its growth. In contrast, legumes, such as soybean, required aerobic conditions. Soybean is usually grown in Indonesia at lowland and after the rice crop harvested. Therefore, a rice-rice-legume crop sequence is commonly adopted in eastern Indonesia. Soybean growing seasons are usually from July to October, where the soil remains relatively dry. Besides, the field can be maintained in unsaturated conditions for up to 8 months if a single rice crop is grown during the wet season [1].

One of the central soybean production in Indonesia is West Nusa Tenggara Province, and its cultivating area was around 68,896 ha, with a total yield of 97,171 t in 2017 [2]. Soybean productivity in West Nusa Tenggara was lower (1.41 t ha⁻¹) than the average national productivity (1.514 t ha⁻¹) [3]. The national productivity of soybean in Indonesia is still low and it only fulfills about 30% of national demand [3]. Low soybean production in Indonesia could be due to several factors, such as soil, climate, pests, and diseases, as well as poor management.

A factor that affects the growth and yield of soybeans is water irrigation. Soybean needs a sufficient water supply during its growth process to achieve high yields [4]. The water irrigation must be sufficient...
during its growth period starting from germination, growth, flowering and pod filling. However, the optimal availability of water is rarely found in the field for soybean growth during the third planting season (July-October). Unsecured water availability is one of the causes of declining yields as soybean planted is not drought tolerant and needs a sufficient water supply to achieve high yields [4,5]. The amount of water requires for soybeans to grow optimal is in the range of 300-350 mm [6] and up to 700 mm depending on genotype characteristics [7]. Thus, the lack of water in the soybean growing period causes growth and yields to decrease. However, frequency irrigation may also affect the yield of soybean. The effect of water shortage in the generative phase is more severe than in the vegetative phase [8]. Lack of water in the flowering phase of soybeans would cause pod formation to fail [9]. Furthermore, soybean plants that experience a shortage of available water (60-70%) in the vegetative phase can still be maintained as long as they are irrigated immediately at the time of flowering. Moreover, soybean yield is most sensitive to water deficits during reproduction. Soil water deficits during reproductive growth phase results in increased flower abortion, reduced pod number, reduced seed per pod, and small seed [10]. Drought stress inhibited increases in the soybean plant height and leaf area. As the stress became more severe, longer, and more frequent, this inhibitory effect became more significant [11].

The physical characteristics of soil affected plant growth such as texture, structure, consistency, porosity, and density. Soybean yields decreased as soil bulk density increased [12]. A similar result was also reported by Botta et al. [13]. Soybean yield was very low (max 1.0 t ha⁻¹) for Alfisol that had a bulk density of 1.29–1.34 g cm⁻³ [14].

The water supply system in the irrigation area of Lombok Island still does not consider the type of soil. The type of soil also affects the amount of water needed by plants. Meanwhile, the amount and duration of irrigation water are the same for all irrigated areas for secondary crops in the third planting season. There are two sources of irrigation water in Lombok Island include surface and groundwater. Irrigation water supplies in many areas of Lombok are declining and requiring farmers to use water more efficiently. However, most farmers in Lombok still use schedule irrigation empirically because the fact that until recently, water has traditionally been abundant and inexpensive as well as due to a lack of easily applicable and scientifically based irrigation scheduling methods and tools. Providing a schedule for irrigation by considering the type of soil will be able to increase the efficiency of water use in the stretch of land. The study aimed was to determine the frequency of irrigation at various types of soil for optimal soybean yields in Lombok.

2. Materials and methods

The experiment was carried out on the third planting season (MT3) from July to October 2017 at different locations depending on the type of soil used. The first location that represents the type of sandy soil was in Rembiga Village, Selaparang District, Mataram City (-8.55934°; 116.107196°). The second experiment location was in Bagek Nunggal Village, Jonggat Subdistrict, Central Lombok Regency (-8.67041°; 116.19622°) representing a loam soil and the third location was in Praya Village, Praya Subdistrict, Central Lombok Regency (-8.692825°; 116.262496°) representing a clay soil (figure 1). The soil characteristics of three experiment sites can be seen in the table below.
Figure 1. Three experiment sites (yellow pin) of soybean at third planting session.

Table 1. Soil properties at the Praya experiment site, NTB Province.

| Soil layers (cm) | pH (1:5) | N-Total (%) | P₂O₅ | K₂O | Na | Ca | Mg | O C (1:5) |
|------------------|----------|-------------|------|-----|----|----|----|-----------|
| 0-20             | 6.93     | 0.059       | 37.45| 90.23| 3.67| 3.80| 1.74| 1.42      |
| 20-40            | 7.36     | 0.029       | 16.11| 110.48| 4.67| 7.99| 3.65| 0.91      |

| Soil layers (cm) | CEC cmol kg⁻¹ | Texture (%) | BD g cm⁻³ | Porosity % |
|------------------|----------------|-------------|------------|------------|
| 0-20             | 43.40          | Sand 26     | 1.22       | 53.9       |
| 20-40            | 34.40          | Sand 31     | 1.32       | 50.1       |

Note: Soil texture at 0-20 cm and 20-40 cm depth: clay.

Table 2. Soil properties at the Jonggat experiment site, NTB Province.

| Soil layers (cm) | pH (1:5) | N-Total (%) | P₂O₅ | K₂O | Na | Ca | Mg | O C (1:5) |
|------------------|----------|-------------|------|-----|----|----|----|-----------|
| 0-20             | 7.13     | 0.064       | 41.42| 61.43| 3.61| 2.82| 1.93| 1.29      |
| 20-40            | 7.46     | 0.041       | 23.15| 80.4 | 4.28| 6.28| 3.41| 0.82      |

| Soil layers (cm) | CEC cmol kg⁻¹ | Texture (%) | BD g cm⁻³ | Porosity % |
|------------------|----------------|-------------|------------|------------|
| 0-20             | 23.48          | Sand 33     | 1.21       | 56.1       |
| 20-40            | 20.12          | Sand 31     | 1.29       | 50.8       |

Note: Soil texture at 0-20 cm and 20-40 cm depth: clay loam.
Table 3. Soil properties at the Selaparang experiment site, NTB Province.

| Soil layers (cm) | pH (1:5) | N-Total (%) | P₂O₅ mg kg⁻¹ | K₂O mg kg⁻¹ | Na % | Ca % | Mg % | O C % |
|-----------------|----------|-------------|---------------|--------------|------|------|------|-------|
| 0-20            | 7.24     | 0.12        | 90.77         | 86.32        | 2.76 | 2.41 | 1.65 | 2.61 |
| 20-40           | 7.36     | 0.08        | 71.93         | 99.54        | 3.65 | 3.24 | 2.15 | 0.80 |

| Soil layers (cm) | CEC cmol kg⁻¹ | Texture (%) | BD g cm⁻³ | Porosity (%) |
|-----------------|---------------|-------------|-----------|--------------|
| 0-20            | 17.31         | 56 Sand     | 1.19      | 55.1         |
| 20-40           | 14.18         | 73 Silt     | 1.35      | 49.2         |

Note: Soil texture at 0-20 cm and 20-40 cm depth: sandy loam and loamy sand, respectively.

The experimental design used in each location was a randomized block design with four irrigation treatments; A. one time irrigation at the age of 15 days after sowing (DAS); B. two times irrigation (15 and 45 DAS); C. three times irrigation (15, 30 and 45 DAS) and D. four times irrigation (15, 30, 45 and 60 DAS). All treatments at each experimental location were repeated 5 times. Plots size were 5 x 6 m² and black polyethylene plastic sheets were inserted to a depth of 0.6 m from the surface in the middle of the bund (mounds to separate adjoining plots) to minimize seepage of water and loss of fertilizer from plots. Bund size was 0.4 m height by 0.4 m width and distance between a block was 1.0 m. Culture management was following integrated crop management of soybean described by Mejana et al. [15]. In brief, no-tillage was applied as it was common practice in irrigated areas in these regions. Certified seed soybean was sown immediately after rice harvesting with 2 seedlings per hill at a spacing of 30 × 20 cm. Rice straw was returned to each plot as mulch for about 1 kg m². Complete fertilizer of NPK (15:15:15) Phonska was applied 10 days after sowing (DAS) at the rates of 100 kg ha⁻¹ (locally as recommended). All weeds and pests were controlled in the field experiment. Weed was removed manually. The insecticide of Decis 1.5 EC (Deltamethrin as the active ingredient) was applied at a rate of 150 mL ha⁻¹ at 23 and 32 DAS to control the pest during the soybean growth period.

Water irrigation was applied based on the treatments (table 4). The amount of water applied during the soybean growth period followed the method calculation described by Brouwer and Heibloem [6]. The amount of water irrigation applied was 23 mm, 46 mm, 112 mm and 65 mm for one, two, three- and four-times irrigation respectively. A water meter tool was installed on each treatment in order to precisely measure water irrigation applied. Rainfall that occurred during the experiment period was recorded and considered for the amount of irrigation applied. Long-term series of rainfall data for each site experiment was also obtained from the nearest climate station.
### Table 4. Amount of water irrigation applied during soybean growth periods at each treatment.

| Month          | Jul  | Aug  | Sep  | Oct  |
|----------------|------|------|------|------|
| ETo            | 3.28 | 3.74 | 3.59 | 4.16 |
| Growth phase   |      |      |      |      |
| Initial        |      |      |      |      |
| flowering      |      |      |      |      |
| Max.           |      |      |      |      |
| ripening       |      |      |      |      |
| total          |      |      |      |      |
| Phase duration (days) | 20   | 25   | 30   | 20   |
| kc each phase growth | 0.35 | 0.75 | 1.1  | 0.6  |
| kc for month   | 0.35 | 0.49 | 1.04 | 0.78 |
| ET Crop (mm day⁻¹) | 1.15 | 1.84 | 3.74 | 3.26 |
| Water need per phase (mm) | 23.0 | 46.0 | 112  | 65   |
| Water application DAS | 15   | 30   | 45   | 60   |
| Water frequency (treatments) | I    | II   | III  | IV   |

The plant was sampled to obtain the effect of treatments on the performance of soybean. Fifteen plants were sampled to determine plant height, dry biomass and 100 seed weight. The dry weight of biomass was recorded after drying samples at 70°C for three days or at constant weight [16]. Soybean was harvested at physiological maturity and expressed at 11% moisture content. A 3 m × 2 m area within each plot of soybean was used to sample grain yield and converted to kg ha⁻¹. Most data were subjected to analysis of variance (ANOVA) using the Genstat Software (Version 9.2.0.153, VSN International Ltd, Oxford). When one or more treatments had a significant effect on measured parameters, the least significant difference (LSD) was calculated to compare mean values of treatments.

### 3. Results and discussion

#### 3.1 Agro-climate of experiment sites

All experiment sites were regarded as irrigated land where rice was planted in the first and second seasons during November-March and April-July, respectively, and the third season from July to October was planted for soybean. However, agroclimatic of experiment sites especially the rainfall pattern was slightly different for each other (figure 2). The average annual rainfall for Praya, Jonggat and Selaparang was 1,555 mm, 1,863 mm and 1,352, respectively. Jonggat and Selaparang rainfall data were taken from the nearest location of Kediri and Ampenan weather stations, respectively. Unfortunately, there was no rainfall event during the plant growth period so the water irrigation resource was fully applied from treatments.

**Figure 2.** Average monthly rainfall for more than 20 years of each experiment site (A: Praya, B: Jonggat and C: Selaparang).
3.2 Agronomic performance of soybean on coarse sandy soil (Selaparang site) at various irrigation frequencies

Agronomic parameters of soybean as influenced by water irrigation treatments. In sandy soil, all agronomic parameters were influenced by water treatments such as plant height, biomass, 100 seed weight and yield (table 5). In general, all parameters increased as irrigation frequencies increased (figure 3). The highest biomass was found at four times irrigation although this was not significantly different with three times irrigation. This trend was also found at plant height and 100 seed weight. The highest yield of soybean was also found at four times irrigation and this was significantly different from all treatments. It indicated that four times the irrigation application was the optimal irrigation frequent to obtain a high yield of soybean in coarse sandy soil type.

| Irrigation treatments | Plant height (cm) | Biomass (t ha$^{-1}$) | 100 seed weight | Yield (t ha$^{-1}$) |
|-----------------------|-------------------|-----------------------|-----------------|-------------------|
| I                     | 54.52a            | 1.72a                 | 9.8a            | 0.55a             |
| II                    | 67.15b            | 5.99b                 | 13.36b          | 1.85b             |
| III                   | 69.07bc           | 7.69c                 | 15.04c          | 2.23c             |
| IV                    | 72.17c            | 8.744c                | 15.66c          | 2.68d             |

**Table 5.** Influence of irrigation frequencies on agronomic performance of soybean at coarse sandy soil type (Selaparang site).

![Figure 3](image.png)

**Figure 3.** Biomass, plant height and yield of soybean as affected by irrigation frequent in course sandy soil type at Selaparang.

3.3 Agronomic performance of soybean at various irrigation frequencies on loam soil type (Jonggat site)

The influence of irrigation frequencies on the soybean performance in loam soil type is presented in table 6. All agronomic parameters were significantly influenced by irrigation frequencies. The highest yield was found at four times irrigation although that was not significantly different with three times irrigation but was significantly different with two and one times irrigation. This trend was similar to plant height and 100 seed weight of soybean. Biomass at treatment four was also significantly higher than other treatments. These trends can also be observed in figure 4 where yield, biomass, plant height and 100 seed weight increased as frequent irrigation increased. This suggested that optimal soybean yield could be obtained with three-time irrigation although the maximum yield was obtained from the four times irrigation. The result of this study was similar with Nurhayati [17], where soil type significantly affected all components of growth and yield of soybean, as well as the amount of cumulative water need of soybean.
Table 6. The effect of irrigation frequencies on agronomic parameters of soybean on loam soil type (Jonggat).

| Irrigation treatments | Plant height (cm) | Biomass (t ha⁻¹) | 100 seed weight | Yield (t ha⁻¹) |
|-----------------------|------------------|------------------|----------------|--------------|
| I                     | 58.17a           | 3.03a            | 8.48a          | 0.67a        |
| II                    | 67.5b            | 5.44b            | 14.86b         | 1.83b        |
| III                   | 76.17c           | 7.05c            | 14.73b         | 2.31c        |
| IV                    | 77.25c           | 9.26d            | 15.79b         | 2.52c        |

Figure 4. Biomass, plant height and yield of soybean as affected by irrigation frequently in loam soil type at Jonggat.

3.4 Agronomic performance of soybean at various irrigation frequencies on clay soil type (Praya site).

The agronomic parameter of soybean as influenced by frequent irrigation on clay soil type (Praya) is presented in table 7. The trend of the influence of frequent irrigation on agronomic parameters of soybean was similar to the loam soil type. All parameters such as plant height, dry biomass, 100 seed weight and yield of soybean increased as frequent of irrigation increased (figure 5). However, the soybean yield at three times irrigation was almost similar to four times irrigation. Moreover, other parameters also followed a similar trend.

Water stress, as represented in the treatment I and II, significantly decreased yield and agronomic performance of soybean. Several studies reported that limited water irrigation that leads to drought condition during the growth period decreased the yield of soybean [17-19]. The drought stress inhibited the growth development of soybeans such as plant height, leaf area and reduced chlorophyll content [18]. The results of this study showed that as water irrigation frequencies increased, yield and agronomic parameters of soybean increased. The water needs for soybean plants at the generative phase was higher than that vegetative phase, so that the generative phase is more sensitive to drought condition especially at flowering to pods filling phase [16].
Table 7. Agronomic parameters of soybean as influenced by frequent irrigation in clay soil type (Praya).

| Irrigation treatments | Plant height (cm) | Biomass (t ha\(^{-1}\)) | 100 seed weight | Yield (t ha\(^{-1}\)) |
|-----------------------|-------------------|--------------------------|-----------------|---------------------|
| I                     | 62.21a            | 2.47a                    | 11.01a          | 0.92a               |
| II                    | 65.49b            | 3.03b                    | 10.64a          | 1.23b               |
| III                   | 68.8c             | 3.62bc                   | 12.98ab         | 1.57c               |
| IV                    | 69.67c            | 3.8c                     | 15.65b          | 1.62c               |

Figure 5. Biomass, plant height and yield of soybean as affected by irrigation frequent in clay soil type (Praya site).

3.5 Relation of soil clay content and soybean yield at limited and unlimited irrigation

The relationship of texture (clay contents) of soil and soybean yield on limited and unlimited irrigation is shown in figure 6. Limited and unlimited irrigation here refers to one and four-times irrigation, respectively. In limited irrigation, soybean yield increased as clay content increased, but the reversed condition was occurred on unlimited irrigation, where soybean yield decreased as soil clay content increased. This indicated that the physical characteristics of soil affected the yield of soybean such as texture, structure, consistency, porosity, and density [20]. Soybean yields decreased as soil bulk density increased [12]. Similar result was also reported by Botta et al. [13]. The soil used in this experiment indicated that bulk density increased as clay content increased which was in agreement with soybean yield on unlimited irrigation. Soybean yield was very low (max 1.0 t ha\(^{-1}\)) for Alfisol that had a bulk density of 1.29–1.34 g cm\(^{-3}\) [14].
Figure 6. Relationship of soil texture (clay contents) and soybean yield on limited and unlimited irrigation.

4. Conclusions

Water irrigation frequently influenced soybean yield and agronomic parameters although this effect varied due to soils type variation. On coarse sandy soil type, the highest yield of soybean was obtained from four times irrigation. On loam soil type, the highest yield of soybean was also observed at four times irrigation, although this was not significantly different with three times irrigation. A similar trend of soybean yield occurred at the clay soil type with three times irrigation. The study implied that an irrigation schedule based on soil type should be made for each location for supporting a higher soybean yield.

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