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# Analysis of Crop Water Requirement for Maize with Planting Hole System under Dry Climate Condition

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## ABSTRACT

Crop water requirement is an important factor to increase water use efficiency and avoid crop failure in dryland. A way to increase water use efficiency is by determining an irrigation interval scenario and utilizing a planting hole system. Research on the analysis of water requirement in the planting hole system with an irrigation interval for maize is still limited. Therefore, this study aims to analyze the level of water requirement for maize in dryland. This research was conducted in Camplong Village, Kupang District, East Nusa Tenggara (NTT) from January-May 2020. The design used was a split-plot of various treatments. There were three different techniques of applying fertilizer as the main plot, and two treatments of pruning maize leaves as sub-plots. The different treatments of fertilizer application includes: 1) mixing manure with rice husk charcoal (Ls+As), 2) separating manure from rice husk charcoal (Ls/As), 3) no addition of manure or rice husk charcoal into the planting hole (control). The sub-plots were divided into 2 treatments namely with leaf pruning (P) and without leaf pruning (TP). The water requirement was analyzed based on the FAO 56 approach with the production calculation in weight unit of tiles (*ubinan*). The results showed that 75% water efficiency was achieved or there was a water saving of 3,119 $m^3$/ha/planting season when compared to conventional techniques. The highest maize productivity (7 tons/ha) was attained in treatment of mixing manure with rice husk charcoal with leaf pruning. The result indicated that this water savings may be used to expand the planting area to 3 ha.

KEYWORDS
crop water requirement, dryland, irrigation interval, maize pruning, planting hole system

## INTRODUCTION

Dryland has a big potency for agricultural practices and it covers area of 144.5 million ha or three times higher than wetlands (BPS, 2018). Dryland can be optimized for various primary agricultural commodities in Indonesia, including maize (Sabaruddin et al., 2003; Sun et al., 2022). Generally, maize is the 3rd most widely cultivated food crop (Ahmad et al., 2020), as it has high water use efficiency, high adaptability, and resistance to dry conditions (Soelistyono and Herlina, 2002; Sun et al., 2018; Yang et al., 2018). The annual demand for maize has increased due to population growth and the need for the feedstock and forage industry (Stuart and Houser, 2018).

The utilization of dryland for agricultural practices in Indonesia can be optimized (Adnan et al., 2020; Rejekiningrum and Haryati, 2002). Dryland is mostly left uncultivated as fallow land, especially during the dry season therefore it becomes more prone to erosion and climate change impacts (Irianto, 2011; Rodriguez-Caballero et al., 2018). Dryland also is characterized by low soil fertility and water availability, which highly depend on rainfall events (Darmijati, 2002; Gherardi and Sala, 2019). This characteristics only allow dryland to be used in agricultural practices as long as it is supported by the application of agricultural technology and irrigation (Aryal et al., 2020).

East Nusa Tenggara (NTT), Indonesia, has a total dryland area of 3.35 Mha (Adar and Bano, 2020). However, only few area is for crop cultivation (Koesmaryono et al., 2014). Agricultural activity in NTT is highly dependent on climate factors, especially rainfall (Mulyani and Suwanda, 2020). The high rainfall intensity at a short duration, will cause erosion and decrease soil fertility (Duniway et al., 2019). These conditions remain research challenges in optimizing maize farming in NTT to meet food demand in the future.

Maize productivity in NTT is low, even in the rainy season, which depends on climate variability (Erythrina et al., 2021). Daily rainfall events are often limited up to 2 weeks, and this short wet spells may trigger drought stress (Kuswanto et al., 2021). To overcome this problem, adaptation activities are encouraged. These activities include increasing the productivity of land resource use and regulating irrigation systems (Michelon et al., 2020). The effectiveness of rainwater utilization can be improved by adding organic matter to increase soil water retention capacity and performing minimal tillage with a planting hole system (Borthakur et al., 2019). Another example is leaf pruning, which may increase the efficiency of capturing sunlight capability thereby increasing productivity (YiZhen et al., 2018). Koesmaryono et al., (2014) reported that maize productivity accompanied by leaf pruning treatment would escalate the productivity.

FAO mentioned that the application of a permanent planting hole system and the use of organic fertilizer such as manure may increase the Planting Index (IP) to 200 (FAO, 2018). In principle, the planting hole system only cultivates the land in the root area, providing a wider reach for plant roots compared to the usual *tugal* system. The soil structure can be preserved from experiencing compaction. In addition, the carbon stored in a minimally cultivated land is not easily released into the atmosphere, but becomes soil fertilizer. The planting hole also functions as a water catchment for surface runoff, retaining the water to infiltrate deeper into the soil (Kimaru-Muchai et al., 2020). In addition, water retention capacity of the soil can also be increased by adding organic matter such as manure or rice husk charcoal to the planting hole. The research aims to analyze the level of water requirement for maize on dryland in arid region using a planting hole system with organic fertilizer application to increase maize productivity.

## RESEARCH METHODS

### Research design

We built a research field in Camplong Village, Fatuleu District, Kupang Regency, East Nusa Tenggara Province. Geographically, it is located at 10°1'57” S and 123°56'55” E with an altitude of 389.5 masl. In the field, we planted the Lamuru variety seeds for period of Jan-May 2020. Podsolic soil is found in this area, which typically has a low fertility (Table 1). The area is relatively flat with a slope of 8-15%.

The research was arranged in a split-plot design with 3 treatments. The control treatment used a 2-years old planting hole that had not been used. The holes for the control treatment were directly dug into the previous planting holes. The main plot consisted of 3 treatments of fertilization techniques, namely (1) application of mixed manure and rice husk charcoal (Ls+As), (2) application of separated manure and rice husk charcoal (Ls/As), and (3) without the application of manure or rice husk charcoal as control treatment. For each main plot, there were two sub-plots with additional treatment, namely (1) with maize leaf pruning (P) and (2) without maize leaf pruning (TP). Leaf pruning was performed when the maize entered the final generative phase (70 days after planting) by trimming the lower leaves to one leaf below the cob.

**Table 1.** Characteristics of soil chemistry at the research site.

| Position and Type Soil Sample | Parameter | | | | | | |
|---|---|---|---|---|---|---|---|
| | pH | | Organic C | N Total | C/N Ratio | $P_2O_5$ Available | Cation Exchange Capacity |
| | $H_2O$ | *N* KCl | | | | | |
| | - | - | % | % | - | Mg/Kg | *C* mol(+)/kg |
| Outside the planting hole with a depth of 0-40 cm | 7.70 | 6.02 | 1.96 (R) | 0.1(R) | 14(R) | 7.64(SR) | 25.93(T) |
| Soil in the old hole | 7.95 | 6.95 | 5.41 (ST) | 0.4(S) | 15(S) | 82.56(ST) | 33.19(T) |
| Pure manure | 7.90 | 7.64 | 25.3 (ST) | 2.2(ST) | 12(T) | 40.66(ST) | 46.9(ST) |

note: SR (Very Low), R (Low), S (Medium), T (High), ST (Very High)

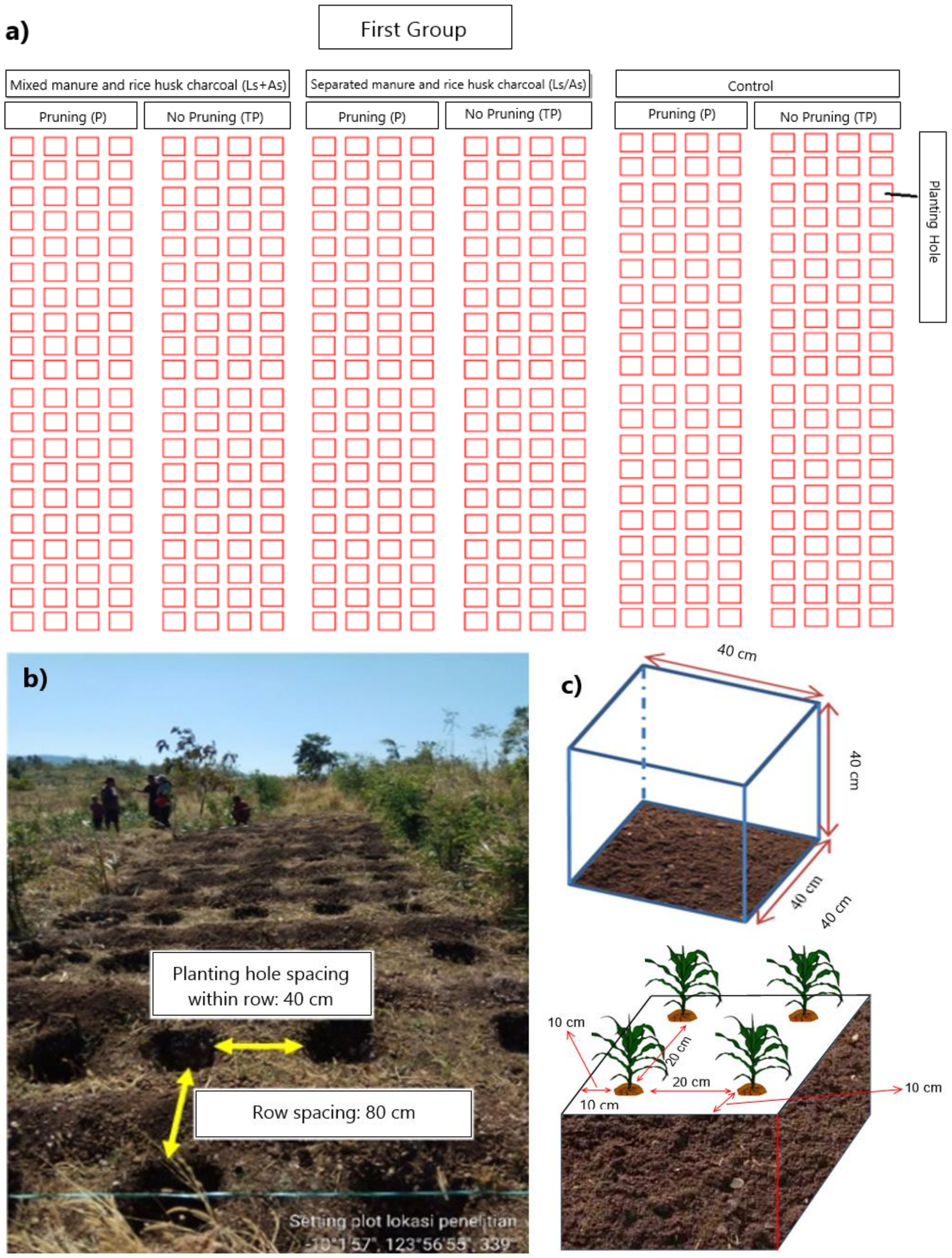

**Figure 1.** Research design in the field: a) plots for each treatment, b) a photograph of planting hole dimension, and c) the dimension of each planting hole.

The digging process for the planting hole was carried out at a predetermined location with a total experimental unit of 1,440 holes for all treatments. Each planting hole had a dimension of 40 cm x 40 cm x 40 cm and consisted of 4 maize crops each. Each treatment group had the same number of planting holes. The design of the planting hole plot which was used in the study is presented in Figure 1. Each planting hole was filled with 4 Kg of manure and 1.3 Kg of rice husk charcoal. The charcoal in this research had the pH of 8.3, C-Total 30.76%, N 0.05%, P 0.023%, K 0.06%, and water retention capacity of 40%.

## Water Availability

Water availability in the research area was estimated from the soil water content. We sampled soil to obtain field capacity and the wilting point through soil physical analysis. The maize water requirement then was considered as the basis for irigation scenarios. The water requirement analysis was important since maize had a varying daily water requirement depending on the growth phase (Mirhashemi and Panahi, 2021).

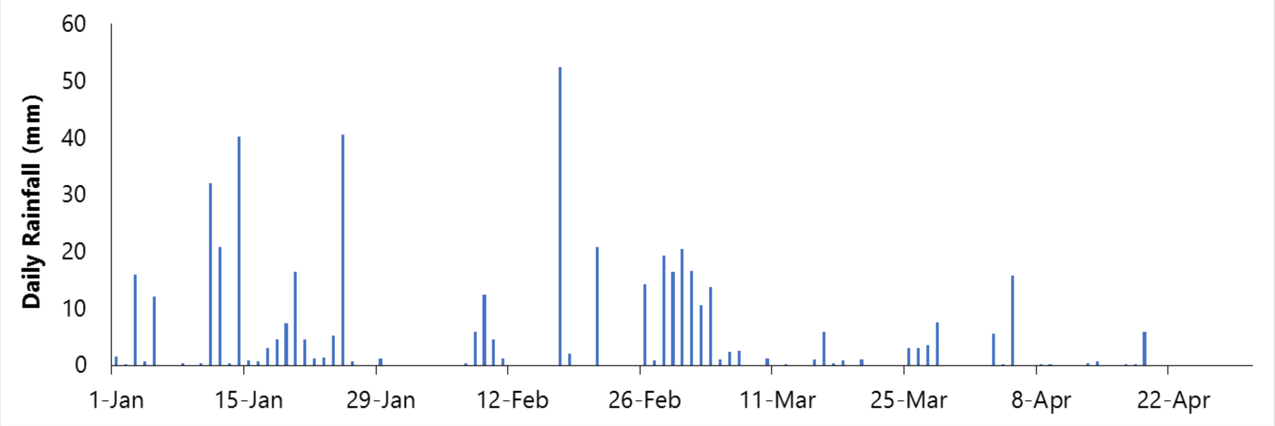

**Figure 2**. Daily rainfall in Kupang for January-April 2020.

### Irrigation Requirement

Irrigation requirement was determined based on climate and physical and chemical characteristics of soils. The characteristics will determine the soil ability to absorb and reserve water after irrigation. As the uncertainty of rainfall events in Kupang, the watering time was determined by observing the crop condition. If the crop did not experience any stress despite no wet spells in 2 weeks, then watering was not performed until the final generative phase. The irrigation interval scenario was calculated to estimate the water requirement based on the growth and development phases of maize. The preferred scenario of the irrigation interval was irrigation per 3-days for each planting hole. The scenario selection was also intended to test the planting hole ability to preserve soil moisture during no rainfall events.

The irrigation interval was referred to the ratio between the Net Irrigation Depth (NID) for each plant growth phase to the cumulative daily irrigation requirements. Determination of water requirements was determined using the equation ETc (mm) = Kc x Eto (mm), where ETc = crop evapotranspiration, which indicated crop water requirements, Kc = crop coefficient and Eto = reference evapotranspiration. ETo was calculated based on Penman equation (Penman, 1948). The water use efficiency was calculated using the EPA equation (Zhang et al., 2019) as dry weight of plants/water requirement.

### Pruning Maize Leaves

There were two types of sub-plot treatments carried out in this study (Figure 1a), namely: 1) with maize leaf pruning (P) and 2) without maize leaf pruning (TP). Pruning was performed when the maize entered the generative phase at 6-7 weeks after planting and the maize cob was filled. The pruning was performed for about three or six leaves, started from one leaf below the cob to the ground.

### Observation of Plant Growth and Productivity

Maize growth was observed by measuring plant height and leaf width. Plant height measurement was started at 2-11 weeks after planting, while leaf width measurement was at 1-11 weeks after planting. The leaf measuring was made at the center of the widest leaf in the plant. For each plot, 4 individual plants were randomly selected to be measured. Other parameters that were also observed were yield and productivity, which was measured from kernel weight, the cob weight, and the dry kernel tiles weight

### Statistical Analysis

The data obtained were analyzed using SAS software. We analyzed variance with post hoc Duncan Multiple Range Test (DMRT) (Allen, 2017) at $\alpha$=0.05.

## RESULTS AND DISCUSSION

### Climate in the Study Site

Maize was cultivated during rainy season. Figure 2 shows the daily rainfall for January-April 2020 in study site. The best planting time based on the existing rainfall was in the 1st and the 2nd weeks of January with total rainfall of 212.2 mm. Based on a monthly evapotranspiration of 150 mm, rainfall in January was sufficient to moisten the land and it was suitable for the growth of maize in the early vegetative phase. In wet months, days without rainfall last for 5-14 days. However, during the research, the maize did not experience any water stress although no watering was carried out.

### Water Availability in the Study Site

The onset date of dry season was defined as a date Soil water availability at the study site was different for each phase of plant development. Field capacity at the study site was 26.4% and wilting point of 15.6%. In our study, maize required water for its development depending on growth phase. During vegetative phase, maize needed 21 mm of water as

**Table 2**. Soil water availability in the study site.

| Growth Phase | Length (Days) | ETp | Kc | ETc | Net Irrigation (mm) | Daily Irrigation (mm) |
|---|---|---|---|---|---|---|
| Germination and emergence | 20 | 4.1 | 0.30 | 1.23 | 7 | 1.2 |
| Vegetative growth | 30 | 4.3 | 1.15 | 4.95 | 21 | 4.2 |
| Reproductive development | 30 | 3.6 | 1.15 | 4.14 | 21 | 3.5 |
| Kernel development | 10 | 3.7 | 0.60 | 2.22 | 28 | 2.0 |

note: ETp and ETc denoted potential and crop evapotranspiration (mm/day), Kc is crop coefficient

same as at flowering phase. More water was required during kernel development (30%) higher compared to the reproductive phase (Table 2). In each phase, maize growth was supported by water irrigation. During germination and emergence phase, daily irrigation was 1.2 mm and it was 4.2 mm for vegetative phase. Less water was required for final phase development (2 mm).

The result from each analysis was defined as a reference in determining the amount of additional irrigation to meet crop water requirement in a cycle. For a complete cycle (90 days), the total water requirement of maize was 312.0 mm (Table 3), while the available water based on the results of soil physical analysis was only 130.4 mm. Given the influence of the development of plant roots access that differ in each phase, the available water that will be used by maize or Readily Available Water (RAW) also changes. Readily Available Water in the germination and emergence, vegetative growth, reproductive development, and kernel development was 6.5 mm, 19.6 mm, 19.6 mm, and 26.1 mm, respectively.

### Water Requirement of Maize in the Planting Hole System

The estimation of crop water requirement is important to allow efficient water use (Virnodkar et al., 2020). Increasing water use efficiency can be done by applying irrigation interval based on water stress limit and increasing water retention capacity of the soil by modifying the planting media. The total daily irrigation required for a complete maize growth cycle (90 days) was 311.9 mm. However, the available water in the research site based on the soil physical analysis (130.4 mm) was not sufficient to meet this requirement, and additional water irrigation was needed. This calculation was important to prevent plants from experiencing water stress (Song et al., 2019).

Based on Table 4, the irrigation dosage for each planting hole in 3-days interval scenario was 0.5 liters. A hectare area with a 20 cm x 20 cm spacing consisted of 62,500 crops required irrigation dosage of 8,152.4 liters for germination phase, 36,685.7 liters for vegetative phase, 29,348.6 liters for reproductive phase, and 16,304.8 liters for kernel development phase, using the same intervals scenario. In contrast to conventional technology which used a 70 x 40 cm spacing in a *tugal* system, a hectare area consisted of 35,714 crops. Thus, the total water requirement with the same interval scenario for each growth phase was 32,609.3 liters for germination phase, 146,741.6 liters for vegetative phase, 117,393.3 liters for reproductive phase, and 65,218.5 liters for kernel development phase.

Similar to this research, previous finding revealed that there was also a difference in the amount of water required for each phase of plant growth in *Medicago sativa* (Huang et al., 2018). Similar finding was also present in Udom and Kamalu (2019) research, who reported that a 20-30 cm maize with a water requirement of 2.5 mm/day entered the kernel deve-

**Table 3**. Water requirement of maize and irrigation dosage for each development phase.

| Growth phase | Length (days) | Available water (mm/m) | Maximum root access (m) | Total available water (mm) | Soil water subsidence fraction (p) | Readily Available Water (mm) | Irrigation dosage (mm/day) | Total crop water requirement (mm) |
|---|---|---|---|---|---|---|---|---|
| Germination and emergence | 20 | 130.4 | 0.10 | 13 | 0.5 | 6.5 | 1.09 | 21.7 |
| Vegetative growth | 30 | | 0.30 | 39 | | 19.6 | 3.8 | 117.4 |
| Reproductive development | 30 | | 0.30 | 39 | | 19.6 | 4.9 | 146.7 |
| Kernel development | 10 | | 0.40 | 52 | | 26.1 | 2.6 | 26.1 |
| Total | 90 | | | 143 | | 71.8 | | 311.9 |

**Table 4**. The level of water requirement for irrigation in the planting hole system.

| Growth phase | Length (days) | Daily irrigation dosage (mm/day) | Planting hole system in 3-days irrigation interval scenario | | Tugal system in 3-days irrigation interval scenario | |
|---|---|---|---|---|---|---|
| | | | Irrigation dosage for each planting hole (liter) | Irrigation dosage per hectare area (liter) | Irrigation dosage for 4 populations with 70 x 40 cm spacing (liter) | Irrigation dosage per hectare area for 35,714 populations (liter) |
| Germination and emergence | 20 | 1.09 | 0.5 | 8,152 | 3.7 | 32,609 |
| Vegetative growth | 30 | 4.89 | 2.3 | 36,685 | 16.4 | 146,741 |
| Reproductive development | 30 | 3.91 | 1.9 | 29,348 | 13.1 | 117,393 |
| Kernel development | 10 | 2.17 | 1.0 | 16,304 | 7.3 | 65,218 |

lopment phase, the water requirement increased to 10.2 mm/day. Djaman et al., (2018) also reported that the water requirement of maize varied during initiation phase, vegetative phase, flowering phase, and seed filling phase, which was 30.8 mm, 102.49 mm, 117.50 mm, and 2.69 mm, respectively.

The crop population difference between the planting hole and conventional *tugal* system also affected the level of water use efficiency. The planting hole system was able to save 75% of water when compared to conventional systems. The water savings resulted from this comparison can be seen in each growth phase, including 24,456.9 liters saved in germination phase, 110,055.9 liters saved in vegetative phase, 88,044.7 liters saved in reproductive phase, and 48,913.5 liters saved in kernel development phase. The water saving capability was also allowed by the addition of the organic matter to the planting hole (Deng et al., 2019; He et al., 2020). Glaser et al., (2002) and Kapoor et al., (2022) stated that the addition of charcoal/biochar to agricultural soils served to increase nutrient availability and water retention. Furthermore, biochar also increase soil moisture and agricultural land fertility (Azeem et al., 2019; Mosharrof et al., 2021; Rawat et al., 2019).

The irrigation interval scenario was applied if there was no rainfall event up to a predetermined interval limit. If there was a rainfall event before the interval limit, the scenario will be applied for the next period. Based on daily rainfall data in January-May 2020 (Figure 2), there were 22 periods without rainfall events for 3-4 days, so the irrigation interval scenario was carried out according to the previous analysis. The planting hole with additional mixture of manure and rice husk charcoal induced a beneficial effect on maize growth, especially in regards to maintain freshness and prevent drought stress. Azeem et al., (2019) reports that rice husk charcoal can increase soil fertility, crop productivity, and carbon sequestration for climate change mitigation.

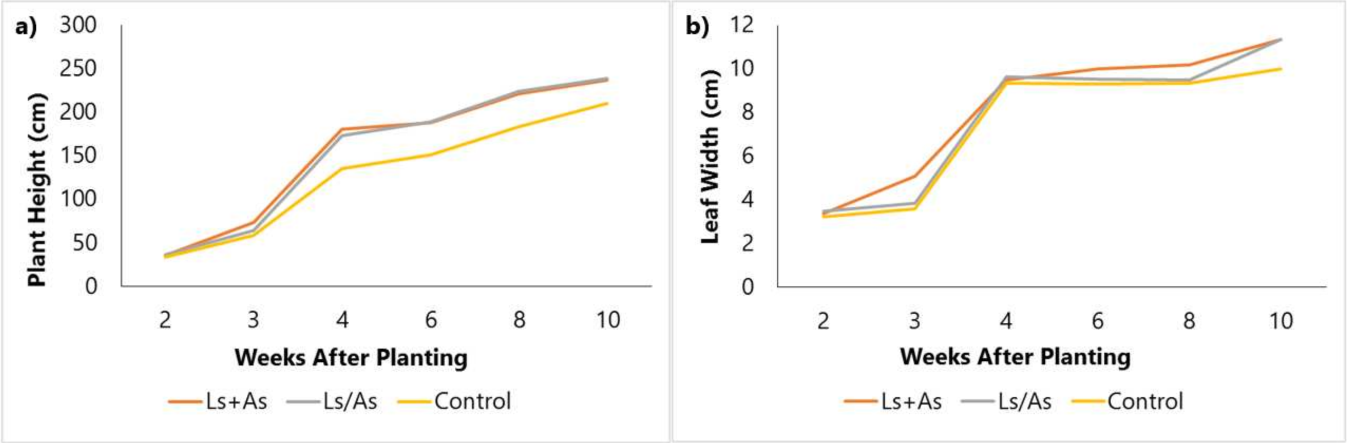

**Figure 3.** Growth of maize: a) plant height (cm), and b) leaf width (cm) with various treatments. Ls+As denotes mixing manure with rice husk charcoal, Ls/As denotes separating manure with rice husk charcoal, and Control denotes no addition of either manure or rice husk charcoal.

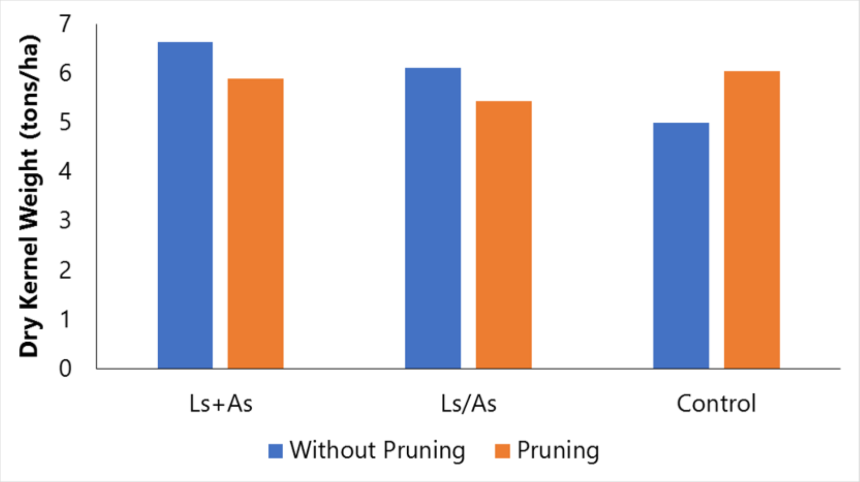

**Figure 4.** Dry kernel productivity of main plots and sub-plots during observation from January-April 2020

### Maize Growth and Productivity in the Planting Hole System

Maize growth was measured through plant height and leaf width. Utilization of planting holes with organic manure and rice husk charcoal had a significant effect ($p<0.05$) on maize within 2-10 weeks after planting. Maize height from the treatment of organic fertilizer and rice husk charcoal addition (either mixed or separated) had a higher value compared to control treatment. Maximum maize height occurred at 10 weeks after planting (Figure 3).

Figure 3 shows that the maize height and leaves width increased along with increasing plant age. The most significant changes occurred in the third to the fourth week after planting. This occurred due to a better nutrients absorption since the plant roots have developed well. In addition, the growth of the leaf size also resulted in a better solar radiation absorption to produce more assimilate in large quantities.

There were differences in the maize height according to the main plot treatment applied. The application of manure mixed with rice husk charcoal (Ls+As) resulted in higher plant height than the control treatment (without the application of manure or rice husk charcoal). Meanwhile, the maize height from either mixing manure with rice husk charcoal (Ls+As) or separating manure from rice husk charcoal (Ls/As) was not significantly different. In contrast, the three main plot treatments, i.e Ls+As, Ls/As, and control did not result in significant differences in terms of maize leaf width.

### Yield Productivity

The application of manure mixed with rice husk charcoal (Ls+As) resulted in the highest maize productivity, especially in terms of weight of shelled maize as shown in Figure 4. Based on Figure 4, maize production from mixing manure with rice husk charcoal (Ls+As) treatment without leaf pruning resulted in a tons/ha kernel weight maize. Meanwhile, the same main plot treatment with leaf pruning resulted in a 6 tons/ha maize. Separating manure with

**Table 5.** Comparison of kernel weight, cob weight, and productivity in main plots and sub-plots of maize with different organic fertilizer application techniques.

| Main plot Treatment | Kernel Weight (gr) | Cob Weight (gr) | Tile Kernel Weight (tons/ha) | Tile Kernel Weight (gr/ha) |
|---|---|---|---|---|
| Ls+As | 49.10 a | 57.63 a | 8.71 a | 793.67 a |
| Ls/As | 40.10 b | 46.17 b | 7.97 b | 673.17 b |
| Control | 31.47 c | 34.17 c | 1.35 c | 517.50 c |

| Sub plot Treatment | Kernel Weight (gr) | Cob Weight (gr) | Tile Kernel Weight (tons/ha) | Tile Kernel Weight (gr/ha) |
|---|---|---|---|---|
| Pruning | 40.91 a | 47.78 a | 1.72 a | 664.56 a |
| No pruning | 39.53 a | 44.20 a | 1.73 b | 658.33 b |

note: a, ab, bc, and c are the ranking code for the average value of treatment consecutively from largest to smallest which used to determine the difference in effect between treatments by Duncan's Multiple Test Results (DMRT). Numbers in the same column followed by the same letter shows no significant difference in the DMRT test level of 5%

rice husk charcoal (Ls/As) resulted in a kernel weight of 6.1 tons/ha without leaf pruning and 5.4 tons/ha with leaf pruning. The control treatment resulted in a shed weight of 6 tons/ha without pruning and 5 tons/ha with pruning. The result of statistical analysis showed that the main plot treatment had a significant effect on the production of dry shelled/kernel maize.

The application of mixed manure and rice husk charcoal resulted in the highest production. This productivity exceeded previous research, which was achieved by the application of mixed chemical fertilizers and manure (Hua et al., 2020; Kandil et al., 2020). Another finding showed that the application of rice husk charcoal as a soil enhancer was able to increase the crop productivity (Giono et al., 2021; Singh Karam et al., 2021). Rice husk charcoal was also reported to increase the absorption of nitrogen nutrients (Asadi et al., 2021; Ghorbani et al., 2019; Koyama and Hayashi, 2019).

Table 5 shows the influence of each treatment on kernel weight, cob weight and maize crop productivity. It shows that the main plot treatment had a significant effect on the differences in maize productivity in terms of kernel weight, cob weight, and dry kernel tile weight. The highest maize productivity was from the Ls+As treatment compared to other treatments. Mixing manure and rice husk charcoal could optimize nutrient absorption and soil water retention, resulting in higher maize productivity. Meanwhile, the results of the sub-plot treatments showed that the kernel weight, cob weight, and the dry kernel tiles weight were not significantly different either with or without leaf pruning. Thus, maize leaves from pruning can be used as forage. Leaf pruning can increase the efficiency of capturing sunlight by plants (YiZhen et al., 2018). Leaf pruning in maize has caused morphological changes and increased crop productivity in the Xinjiang region of China (Liu et al., 2020).

## CONCLUSION

The utilization of the planting hole system in dry land with dry climate can achieve 75% water use efficiency for maize cultivation or equivalent to 3,119 $m^3$/ha/planting season when compared to conventional techniques. The highest corn productivity (7 tons/ha) was attained using the combination treatment of mixing manure with rice husk charcoal followed by leaf pruning.

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