Effect of organic amendments on maize cultivation under agricultural drought conditions in Central Java, Indonesia

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Abstract:

This study examined the effect of three organic amendments – compost (CP), sugarcane bagasse (SB), and rice husk ash (RA) – on soil moisture and maize growth in rain-fed farmland under agricultural drought conditions in Central Java, Indonesia. The wet organic amendments were applied at a rate of 20 t ha<sup>-1</sup> and mixed into the root zone 3 days before seeding. Chemical fertilizers were not included in any treatment during the experiment. CP and RA kept the soil moisture above the soil suction of pF 1.0 between initial planting and harvesting. By contrast, SB treatment exacerbated the impact of the agricultural drought compared with the control (CO) or no organic material. The maize yields of CP (690 kg ha<sup>-1</sup>) and RA (538 kg ha<sup>-1</sup>) were higher than those of CO (456 kg ha<sup>-1</sup>) and SB (382 kg ha<sup>-1</sup>); all yields were lower than the regional average in Central Java (698 kg ha<sup>-1</sup>). Maize yield was correlated with the lowest soil moisture value ($R^2 = 0.80$). Overall, CP and RA substantially reduced the damage to rain-fed farmland caused by agricultural drought. The lowest soil moisture value was a major explanatory factor with respect to the yield gap of maize under agricultural drought conditions.

KEYWORDS agricultural drought; organic amendments; soil moisture; rain-fed farmland; maize; yield

INTRODUCTION

Drought is an extreme weather phenomenon and a complex, slow-onset ecological challenge that causes serious economic, social, environmental, and agricultural productivity losses (Smit and Wandel, 2006). According to United Nations Agenda 2030, sustainable development goal 12 (SDG 12) includes sustainable management and efficient use of natural resources (Target 12.2) and environmentally sound management of chemicals and all wastes throughout their life cycle by 2020 (Target 12.4) for sustainable consumption and production and environmentally sound technologies (United Nations, 2019). Strategies to alleviate drought damage are necessary to support sustainable agriculture such as soil moisture. Generally, soil moisture depletion greatly affects maize growth and leads to maize yield reduction (Kramer, 1944; Denmead and Shaw, 1960; Uwizeyimana et al., 2018), especially in rain-fed farmland, where drought is common.

Approximately 54% of farmland globally is rain-fed and these areas contribute up to 80% of global agricultural production (Devendra, 2012); 62% of the global production of staple foods comes from rain-fed farmland, including maize (Hulugalle et al., 2017). Maize is one of the most important crops in Indonesia and is planted on 19% of the total crop land (Badan Pusat Statistik, 2018); 89% of that area is rain-fed farmland (Swastika et al., 2004). Rain-fed farmlands are vulnerable to soil moisture deficits because water is available only from rainfall events, and the capacity of individual farmers to adapt to water deficits is limited (Rockström et al., 2010; Ariyanto et al., 2016). Therefore, the soil moisture is a key factor in agricultural drought, and directly influences soil properties, growth, and crop yield (Darkwa et al., 2016).

Studies have focused on maintaining soil moisture using various methods, such as mulching using plastic (Abouziena and Radwan, 2015), paper (Kader et al., 2017), and geo-textiles (Zrbi et al., 2015). However, those materials can cause environmental issues and have high costs. Iizumi et al. (2018) reported new agronomy strategies to adapt to drought conditions and maintain soil moisture, including organic amendments.

Some studies have reported that organic amendments enhance soil moisture and quality in rain-fed farmland, although results have varied (Mbah and Onweremadu, 2009; Teixeira et al., 2015; Schmid et al., 2017; Aller et al., 2017). However, very little is known about the effects of organic amendments to alleviate severity of agricultural drought considering a relationship between soil moisture and maize growth. Therefore, this study examined the effects of various organic amendments on soil moisture and maize growth in rain-fed farmland under agricultural drought conditions.
MATERIALS AND METHODS

Experimental design

A field experiment was conducted in rainfed farmland in Gondangrejo District, Karanganyar Regency, Central Java, Indonesia (7°29’45’’S, 110°51’25’’E) during the dry season (between July 10 and November 12, 2018). The mean average temperature and rainfall from 1998 to 2018 were 27.7°C and 2,588 mm y⁻¹ respectively. The soil texture was categorized as a sandy clay with 51.2% sand, 11.5% silt, and 37.4% clay. Typical farming practices were followed, including annual crop rotation of paddy–paddy–Palawija (maize and/or mung bean), where a small farm reservoir (SFR; Figure 1) was used for supplemental irrigation; 10 mm of water was supplied 0 and 18 days after planting (DAP) and 20 mm of water was supplied 28 and 51 DAP.

Raised beds measuring 2 m × 1 m were prepared and the maize cultivar BISI-2 was planted in rows spaced at 0.7 m × 0.25 m with a plant density of 8 stems m⁻². BISI-2 has two cobs per stem and a 120-day growth period, and is commonly used by local farmers. A randomized complete block design with four replications was used.

The experimental treatments included compost (CP), rice husk ash (RA), and sugarcane bagasse (SB), along with a control (CO) in which maize was cultivated without any organic material. The experimental plots were treated with 20 t ha⁻¹ of wet organic amendments based on the practices of local dairy farmers and mixed in the root zone (20–25 cm soil depth) 3 days before seeding. The particle size of CP and RA ranges 3–5 mm (compost garden waste) and 4.75–13.20 mm (burnt rice husk ash), respectively (Verma et al., 2015). Chemical fertilizers were not included for any treatments and the control during maize cultivation. Soil bulk density was measured as described by Moroizumi and Horino (2004). The value of the parameter of the soil-water characteristic curve (SWCC) and set to 1.23 corresponding to the soil type of sandy clay (Morozumi and Horino, 2004). The value of n is modeled by the bulk density and the fine particles content (fraction of silt and clay) (Assouline, 2006). In this study, the particle sizes of organic materials were much larger than silt or clay and we assumed that the value of n should be the same as the original soil. The parameter m was calculated as $m = 1 - 1/n$. The parameter $\theta_s$ is close or equal to zero for a properly measured SWCC (van Genuchten et al., 1991, Tian et al., 2018). The parameters $\theta_s$ and $\alpha$ were estimated following Rawls et al. (1982), and Mualem and Assouline (1989) and Assouline (2006), respectively, as follows:

$\theta_s = 1 - \frac{\rho_s}{\rho}$  

$\alpha = (\rho_s)^n$  

where $\omega$, $\rho_s$, and $\rho$ are a constant coefficient (equal to 3.72), the bulk density (g cm⁻³), and the particle density (g cm⁻³), respectively.

Maize growth and yield analysis

The growth and yield of maize were assessed based on morphometric parameters, including plant height and number of leaves per plant. Seven plants were selected randomly from each plot. Plant height was measured with a tape measure from the base of the plant to the first tassel branch every 10 days from 10 to 120 DAP. Grain yield was

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Figure 1. Photographs of the small farm reservoir (SFR) on (a) July 1, 2018 and (b) September 20, 2018
measured for each treatment after harvesting. The Tukey test was used to assess differences among the treatments at the 95% confidence level; multiple comparisons were performed. The statistical analyses were conducted using SPSS software (ver. 22.0; SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Precipitation and meteorological drought

No precipitation was recorded until 70 DAP. A meteorological drought in Indonesia is defined as a total amount of precipitation less than 50 mm for 20 consecutive days (Badan Meteorologi, Klimatologi, dan Geofisika, 2018); in this study, the period from 0 to 120 DAP met this definition. The water stored in the SFR was supplied to the field from 0 to 51 DAP, but the SFR dried up after 71 DAP until 108 DAP (Figure 1). The meteorological drought conditions ended on 120 DAP with 99.6 mm rainfall, after two small rainfall events on 71 DAP (17.4 mm) and 108 DAP (15.2 mm) (Figure 2).

Soil moisture and agricultural drought

The bulk and particle density were 0.90 and 2.28 g cm\(^{-3}\) under CP, 0.91 and 2.31 g cm\(^{-3}\) under RA, 0.89 and 2.29 g cm\(^{-3}\) under SB, and 0.93 and 2.38 g cm\(^{-3}\) under CO, respectively. The soil amendment using organic material had the effect of decreasing bulk and particle density (Adams, 1973; Mohammadshirazi et al., 2017; Sax et al., 2017; Kranz et al., 2020).

Soil moisture under the CP and RA treatments was stable compared with that under the CO treatment throughout the experiment period (Figure 2). The average and lowest soil moisture values were pF 0.77 and pF 0.88 under CP, pF 0.88 and pF 1.01 under RA, pF 1.50 and pF 1.91 under SB and pF 1.04 and pF 1.30 under CO, respectively.

The volumetric water content under CP and RA was higher than that under CO, consistent with previous studies reporting that CP and RA increase water-holding capacity (Zemánek, 2011; Schmid et al., 2017; Aller et al., 2017). By contrast, the volumetric water content under SB was lower than that under CO. The mechanism underlying the effect of organic amendment on volumetric water content is not clear and requires further analysis.

Maize growth responses under agricultural drought conditions

Plant height was similar among all treatments until 40 DAP (Figure 2). From 40 to 70 DAP, plant height under CP was higher than under RA and CO; plant height was lowest under SB. After 70 DAP, plant height under RA increased faster than under CO, and came close to that under CP. The average height and yield were 106 cm and 382 kg ha\(^{-1}\) under SB, 112 cm and 456 kg ha\(^{-1}\) under CO, 129 cm and 690 kg ha\(^{-1}\) under CP, and 123 cm and 538 kg ha\(^{-1}\) under RA, respectively (Figure 3); the maize yield, maize height, and average and lowest soil moisture showed similar trends.

In correlation analysis, although both the average and lowest soil moisture values had strong correlations with crop growth, the lowest value was more strongly correlated with the maize growth both in terms of height ($R^2 = 0.90$) and yield ($R^2 = 0.80$). The coefficients of determination for
average soil moisture and height and yield were 0.65 and 0.44, respectively.

We found that CP and RA reduced the damage caused by agricultural drought, whereas SB exacerbated it. In addition, the yield of CP and RA were able to approach from the regional average (698 kg ha⁻¹) in Central Java, where, irrigation and chemical fertilizer were applied (Badan Pusat Statistik, 2018). Correlation analysis suggested that the change in soil moisture explained the crop growth performance, and that the lowest soil moisture value indicated the severity of the agricultural drought better than the average soil moisture over the whole period.

CONCLUSIONS

In this study, we analyzed the effect of organic amendments (CP, RA and SB) on soil moisture and maize growth under agricultural drought conditions in rain-fed farmland in Central Java, Indonesia. CP and RA helped maintain soil moisture with the pF average range being 0.80 to 0.90 throughout the experimental period, and resulted in greater plant height and yield than CO. By contrast, SB had an apparently negative effect on crop growth compared with CO, attributed to the low soil moisture value associated with this treatment. In addition, the lowest soil moisture value was a major explanatory factor with respect to the yield gap of maize under agricultural drought conditions. The results of this study are expected to facilitate efforts to alleviate agricultural drought via organic amendments.

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