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A Study on Adaptation Strategies for Drought on Rainfed Farmland in Jawa, Indonesia

（インドネシア共和国ジャワ島の天水農地における渇水対策に関する研究）

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SUMMARY

Drought can be defined as an extreme precipitation deficit in a particular area for a period and has characteristics are meteorological, agricultural, and hydrological conditions, related to each other as explained in the past research. Drought characteristics are essential for effective drought management interventions and enable the establishment of management such as early warning system and analysis of risk for drought events, which contribute to manage and improve preparation and contingency planning, especially on rainfed farmland, which vulnerable to soil moisture deficit because the water is available only from rainfall events with inadequate irrigation facilities such as small farm reservoirs. Nevertheless, small farm reservoir system has limitation that is the water cannot be available in the long of dry seasons or water will be empty in the ponds if rainy days is short. Moreover, mulching material as plastic, plastic film, and paper are expensive and has problem on eco-friendly issue. Furthermore, the role of organic amendments on soil properties and yield improvement have been discussed widely, but few studies found regarding with it mechanism on drought alleviation on rain-fed farmland as the new finding of this research. In addition, understanding the role of local knowledge as early warning system and climate change adaptation in the past can be strengthening community resilience's as drought adaptation strategies.

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 rainfed farmland under agricultural drought conditions in Central Java, Indonesia. The wet organic amendments were applied at a rate of 20 t ha^{-1} 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 com- pared with the control (CO) or no organic material. The maize yields of CP (690 kg ha^{-1}) and RA (538 kg ha^{-1}) were

higher than those of CO (456 kg ha^{-1}) and SB (382 kg ha^{-1}); all yields were lower than the regional average in Central Java (698 kg ha^{-1}). 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.

In addition, Understanding the effects of local knowledge on actions and decisions taken during a crisis is important; empirical studies and scientific data can be instructive to this end. This study integrated local knowledge (*Pranata Mangsa*) in Jawa, Indonesia, with scientific data on diurnal rainfall, extreme precipitation events, using the Local and Indigenous Knowledge System (LINKS). The results showed that *Pranata Mangsa* has informed aspects of agriculture including crop calendars, crop patterns, and farming activities, for over 1000 years in Jawa. *Pranata Mangsa* also enhances community resilience by mitigating the effects of extreme droughts; this finding was validated using scientific data.

学位論文要旨

干ばつは、特定の地域で一定期間、極端に降水量が不足することと定義され、その特徴は、気象条件、農業条件、水文条件であり、相互に関連している。干ばつの特性は、効果的な干ばつ管理のための介入に不可欠であり、早期警報システムや干ばつイベントのリスク分析などの管理を確立することができます。これにより、特に天水栽培の農地では、土壌水分が降雨時にしか得られず、小規模農家の貯水池などの灌漑設備が不十分なため、土壌水分の不足に脆弱です。とはいえ、小規模農家の貯水池システムには限界があり、乾季には水を確保できず、雨の日が少ないと池の水が空になってしまう。また、プラスチック、プラスチックフィルム、紙などのマルチング材は高価であり、環境に優しいという問題がある。さらに、土壌の特性や収穫量の向上に対する有機物の役割については広く議論されているが、天水栽培の農地における干ばつ緩和のメカニズムに関する研究はほとんどない。さらに、早期警報システムや気候変動適応策としての在来知の役割を理解し、干ばつ適応策としてのコミュニティの回復力を強化することができる。

本研究では，インドネシア・ジャワ島中部の農業的干ばつ条件下の天水農地において，3種類の有機改良材（コンポスト（CP），サトウキビバガス（SB），籾殻灰（RA））が土壌水分とトウモロコシの生育に及ぼす影響を調査した。有機改良材は 20 t ha^{-1} の割合で散布し、播種の 3 日前に根域に混合した。実験期間中、化学肥料はどの処理にも含まれなかった。CP と RA は、植え付けから収穫までの間、土壌水分を pF1.0 以上に保った。対照的に、SB 処理は、対照（CO）または有機物なしと比較して、農業的干ばつの影響を悪化させた。CP（690 kg ha^{-1}）と RA（538 kg ha^{-1}）のトウモロコシ収量は、CO（456 kg ha^{-1}）と SB（382 kg ha^{-1}）の収量よりも高かったが、いずれも中央ジャワの地域平均（698 kg ha^{-1}）よりも低かった。トウモロコシの収量は、最も低い土壌水分値と相関していた（$R^2 = 0.80$）。全体として、CP と RA は、農業的干ばつによる天水栽培農地の被害を大幅に軽減した。また，土壌水分量の最小値は，干ばつによるトウモロコシの収量格差を説明する主要な要因であった。

さらに、危機的状況下での行動や意思決定に対する在来知の影響を理解することは重要であり、そのためには経験的な研究や科学的なデータが参考になる。本研究では、インドネシアのジャワ州における在来知（*Pranata Mangsa*）と、日中の降水量や極端な降水現象に関する科学的データを、Local and Indigenous Knowledge System（LINKS）を用いて統合した。その結果、*Pranata Mangsa* は、ジャワ島で1000年以上にわたり、農事暦、栽培作物、農業活動などの農業の側面を伝えてきたことがわかった。また、*Pranata Mangsa* は、極端な干ばつの影響を緩和することで、コミュニティの回復力を高めていることが、科学的データを用いて検証された。

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I. INTRODUCTION

Extreme hydroclimate (drought) was forecasted to worsen across the Asian region. Rising temperature is strongest over the continental interiors of Asia (Mannig et al., 2018; Dimri et al., 2018). In a period of 105 years (1990 to 2005) precipitation was declined in parts of tropical climate Asia (Hijioka et al., 2014). The rise in temperature is recognized as the main reason for the increasing frequency and intensity of drought (Ummenhofer et al., 2013). The Asian Development Bank (ADB) reports that drought in tropical climate Asia is expected to increase in the future (ADB, 2009), which suffered from a decline in rainfall as the number of rainy days decreased from 1960 to 2000. These conditions may have severe societal, economic, and environmental consequences, which adaptation is needed.

Adaptation to climate change causes extreme hydroclimate events is increasingly urgent (Coninck et al. 2018). The Paris Agreement made historic strides in recognizing adaptation as a critical component of the global response to climate change, explicitly articulating in the Katowice Climate package rulebook for the Agreement a clear mandate for nations to undertake and document adaptation progress (Magnan and Ribera, 2016; Magnan, 2017). Consistent with the global goal, >150 countries (includes tropical climate Asia countries) have included adaptation provisions in their pledges or nationally - determined contributions (NDCs) (Berang-Ford et al., 2019). As climate change impacts on the environment worsen, adaptation is seen as the best remedy (Shaffril et al., 2017). Knowing how adaptation is taking place allows us to document best practices, facilitate early adoption and collective experimentation (Ford et al., 2011), and enable sharing of lessons about what works, where and why.

Despite the need for knowing drought adaptation strategies, there is a significant challenge has hampered. First, there remains no agreed global and local perception for 'drought and adaptation' (either conceptual or operational) especially concern on the climate type such as tropical climate Asia (Miyan, 2015; Dupuis, J. & Biesbroek, 2013). Second, the accessibility and availability data for gathering information of drought is still lack (Agyei, 2018) causes vary local adaptation drought strategies adopted related to a specific region (Zaki et al., 2020), which have repeatedly been identified as a barrier in drought adaptation planning and implementation by government and policy makers (Sam et al., 2020).

The United Nations Environment Programme (UNEP, 2020) defines adaptation as follows: "In human systems, the process of adjustment to actual or expected climate and its effects to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate". Adaptive capacity, community resilience, and strategies adopted in human and natural systems to adjust to uncertainties in the climate should be assessed, along with the frequency and/or severity of climate events (Etemadi et al., 2016). Sensitive systems are needed to ensure survival (Smit et al., 2006).

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 growth and leads to 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 rainfed 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 (Zribi 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.

In addition, local knowledge can increase the resilience of communities, and enables them to develop adaptation strategies, including early warning systems in the face of an uncertain climate (Andersson et al., 2020; Kuruppu et al., 2009; Green et al., 2010). Anthropologists and sociologists have developed theories of local knowledge, dating back to the 1930s and 1940s. For example, Redfield introduced the "folk-urban continuum" concept in 1944 (Fanslow, 2007), according to which risk reduction can only be achieved through a social process as opposed to a technical, engineering-based process (Audefroy et al., 2017). A catastrophic tsunami was predicted by communities in Aceh, Indonesia based on their local knowledge (*Smong*) (Hiwasaki et al., 2014). Local knowledge is also being used to prevent and mitigate damaging phenomena linked to climate variability in Zimbabwe, such as flooding (Mavhura et al., 2013) and droughts (Chisadza et al., 2013). Many studies have characterized local knowledge as a dynamic and complex body of knowledge, practices, and skills that are developed and preserved by towns or communities through their experiences over time. However, no study has assessed whether local knowledge pertaining to agriculture can enhance community resilience by mitigating the effects of floods and drought.

The Local and Indigenous Knowledge System (LINKS) was proposed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a method for integrating local knowledge with scientific studies of disaster risk reduction (DRR) and climate change adaptation (CCA). LINKS has been used to emphasize the relevance and advantages of local knowledge through empirical data. Local knowledge is transmitted from one generation to the next, and may help to mitigate disaster and promote CCA (UNESCO, 2002).

In Indonesia, local knowledge plays a role in improving disaster preparedness. For example, *Smong* played a role in the response to the Indian Ocean earthquakes and resulting tsunamis that occurred in 1907 and 2004 (Hiwasaki et al., 2013). Local agricultural knowledge, including *Aneuk Jame* (in Aceh), *Parhalaan* (in Sumatra), *Paladang Dayak* (in *Kalima*ntan), and *Pranata Mangsa* (in Jawa) has been used to strengthen community resilience to natural disasters over a long period, and can be traced back to ancient agricultural kingdoms (beginning in 700 AD) (Pigeaud, 1960). In 1960, the Indonesian government strictly implemented a national program consistent with the Green Revolution, whereby conventional farming was replaced with modern practices (e.g., mechanization, pesticide use, and changes in crop types) (Mears, 1984; Iizumi et al., 2018). Local knowledge was treated as outdated and unscientific by this program, which led to self-sufficiency in rice production by the 1980s. Indonesia was recognized internationally for its favorable policies with respect to the Green Revolution, even being granted the honor of making a speech to other Food and Agriculture Organization (FAO) member countries (Falcon, 1991), whereas the local knowledge was regarded only as a traditional culture rather than a practical guideline. However, the new practices were criticized in terms of the high costs, land degradation, and use of unsustainable agricultural practices (Nugroho, 2018). Farmer demonstrations also occurred, with one farmer stating: “We were free and able to make our own decisions of what to plant, when to plant, and how to plant based on traditional local knowledge” (Winarto, 2004).

The history of local knowledge over the past 1000 years in Indonesia is rich, especially as it pertains to agriculture, which is the focus of this study. Several important questions remain; for example, can an effective agriculture system be achieved based on local knowledge without scientific data; and how does local knowledge relate to DRR and CCA? Hence, we validated and verify the components of local agricultural knowledge, namely *Pranata Mangsa*, using a scientific approach, and to classify them according to whether they have a scientific basis and can be related to DRR and CCA.

II. LITERATURE STUDY

1. Drought: Conceptual and operational

Drought can be either a common or unusual characteristic of climate (Okorie, 2003). Drought happens in any climate with differing aspects from area to area (Wilhite et al., 2000b). Discovering a usual explanation for drought is not easy because no two droughts have the equal intensity, extent, duration, or effects (Rouault and Richard, 2003). Different studies have attempted to make a common description. There is no entirely agreed description of drought (Wilhite et al., 1992); its variations are regional and ideological.

However, drought definitions can be broadly categorized as either conceptual or operational (Wilhite and Glantz, 1985). Conceptual definition outlines the basic drought concepts with a general description of the physical processes involved, such as shortage of precipitation (meteorological drought), shortage of soil moisture within a period of 3-6 months which causes water stress in plants and a decrease in crop fertility (agricultural drought), shortage of water in lakes and streams within a period of 1-2 years and even more, this condition is closely related to the occurrence of meteorological droughts in the previous period (hydrological drought), and shortage of water for use by society related to water management (Wilhite 2000). None of these are necessarily correct or wrong, and thus, all need to be recognized. On the other hand, operational definition focuses at identifying the onset, duration, and termination of drought episodes including their severity (Mishra and Singh, 2010). Operational definitions aim at providing precise drought-related information to support an effective early warning system (Wilhite et al., 2014).

Apart from the above definitions, a legal definition of drought is also available (Lopez and Iglezias, 2017). In addition to the effect of drought being context dependent, drought definitions such as that of operational drought (Pedro et al., 2015) and socioeconomic drought (Mishra et al., 2010) are also in existence. Generalized definition of drought can be developed only through the aggregation of process-specific instantaneous droughts (Lloyd-Hughes, 2014). But this definition is based on the assumption that these processes are in equilibrium with the long-term climate, thereby overlooking the distinction between drought and water scarcity (van-lonn et al., 2013). Thus, numerous and diverse disciplines adopt different drought definitions depending on the stakeholder's need as well as hydroclimatic variables included (Wilhite, 2000).

A few developed works of literature made definitions of drought which related to the system impressed through it: meteorological drought, agricultural drought, and hydrological drought. The literature reviews on drought classification depend on the perceptions and explanations of the "National Drought Mitigation Centre" (Wilhite et al., 2014). Different drought events usually can continue as a general evaluation progression that indicates various influences on water scarcity. The initial recognition of drought might be useful in producing control plans that decrease the influences and prevent water consumer competitions in the hydrological scheme(Okorie, 2003).

2. Drought: characterization and indices

Droughts can be characterized via their beginning, severity, period, frequency, and geographical magnitude; which can be assessed by statistical methods using historical data on precipitation and additional applicable variables like streamflow (Moneo Laín, 2008) as shown Table 1. Meteorological drought is a phenomenon associated with prolonged and abnormal moisture deficiency. It is usually described by the magnitude and duration of precipitation deficit with respect to the long-term climatology, often analyzed with statistical indicators like the Standardized Precipitation Index (SPI) (McKee et al., 1993). The SPI index, despite its simplicity and wide use, does only account for water supply without AED that could affect the water balance. The PDSI, and its self-calibrated version, show important problems of spatial comparability among regions with different characteristics (Guttman et al., 1998). The SPEI, accounting for water supply and AED, can be sensitive to the method to compute atmospheric evaporative demand (Begueria et al., 2014). In this study we found that Indonesia has meteorological drought assessment, regionally, which has meteorological drought occurs when a total amount of precipitation less than 50 mm for 20 consecutive days (Badan Meteorologi, Klimatologi, dan Geofisika, 2018; Zaki et al., 2020).

Soil moisture is a fundamental variable, acting as a switch and integrator of various water fluxes interlinked in the soil-vegetation-atmosphere system (Teuling et al., 2013), which indices as an agricultural drought. The RSM (Relative soil moisture was estimated the water balance from several methods. Takes climate, soil, and crop variables containing potential evaptranspiration and precipitation; soil physical properties; and crop features and crop management practices (Sivakumar et al., 2011). Agricultural drought is affected by both climate change and human activity on land, but also direct human influences on the hydrological cycle (Tremblay et al., 2020).

Table 1. Meteorological, agricultural, and hydrological drought recognition indices

	Description and use	Advantages	Limitations
Meteorological drought indices			
Standardized Precipitation Index (SPI)	Depend on precipitation possibility for each time scale. Used in a lot of drought management plans.	It can measure for all temporal scale's drought, assistant early warning, and evaluation drought intensity. Valuable for comparison between areas.	Always precipitation distribution cannot be normal.
Deciles	The easy evaluation method is classifying precipitation and deciles. The Australian Drought Watch System Used it.	Easy statistical estimation. Homogeneity in drought categorization	Long historical data series needed for accuracy
Palmer Drought Severity Index (PDSI)	Soil moisture algorithm for uniform areas. Applied in the USA for emergency planning	One of the most popular indices that are significantly useful for estimation of agricultural drought, since it contains soil moisture	Complicated estimations are needed, and data requirements are not always available. Not useful for all orographic circumstances. Classification of the index based on spatial and temporal occurrences

Agricultural drought indices			
Relative Soil Moisture (RSM)	RSM is estimated the water balance from several methods. Takes climate, soil, and crop variables containing potential ET and precipitation; soil physical properties; and crop features and crop management practices (Sivakumar et al.2011). Reported in percentage.	Quantifiable and simulated, expressing how much accessible water in soil for crops	with a poor representativeness on spatial, cannot be applied to paddy field
Crop Water Index (CWDI)	CWDI is based on actual evapotranspiration precipitation and irrigation demands and weight coefficient	To judge if precipitation and irrigation could meet the water need of crops or not	unmeasured, cannot express other factors influence on water utilization and with various coefficients. It needs daily data
Hydrological drought indices			
Standardized Runoff Index (SRI)	Similar to SPI but it used for hydrological parameters of a given area	appreciated for the region that has naturalized streamflow observation data or calibrated runoff simulations, it can establish with independent on climate, where seasonal forecast expertise is low.	It depends on observed or modeled runoff that cannot be proved everywhere
Reclamation Drought Index (RDI)	Estimated in the river basin, contributes with temperature, precipitation, snow, streamflow, and reservoir levels.	It considers evapotranspiration by the contribution of the temperature.	Analyzed for each river basin related to the organization. There is a restriction for comparison capacity.

Surface Water Supply Index (SWSI)	Improved from Palmer Index which consider water accumulated as snowpack	Shows surface water circumstances which also contains water management. Contribute with hydrological and climatic characters.	Analyzed for each river basin which based on management, there is a restriction for comparison capacity. The index cannot show extreme events accurately

Hydrological drought refers to low flow periods with a streamflow or groundwater level deficit under "natural" conditions. Related indicators often include the annual minimum of a streamflow average taken over several consecutive days. A few drought indices are focused on groundwater. Bloomfield and Marchant (2013) developed a methodology based on the SPI approach that uses the monthly groundwater level time series to estimate a Standardized Groundwater level Index (SGI). Mendicino et al. (2008) introduced a Groundwater Resource Index (GRI), which is derived from a distributed water balance model, and showed high correlation between aquifer levels and the Standardized Precipitation Index (Lorenzo-Lacruzet al., 2017).

3. Drought occurrences in tropical climate Asia

The frequency and intensity of natural hazards are increasing globally (Mishra and Singh, 2010). Unlike other extreme hydrological events, drought stiffens its grip over time, progressively destroying the affected area. Tropical droughts are often associated with multi-year climatic cycles and, therefore, interannual variation makes long-term trends hard to detect (Chadwick et al., 2019). However, many model forecasts suggest that drought frequency and intensity in some tropical forest areas will increase over the remainder of this century (Zhang et al., 2015). Based on the evidence provided by Dai (2012), observed global aridity changes up to 2010 are consistent with model predictions. These predictions suggest severe and widespread droughts in the next 30–90 years in Southeast Asia. The region's annual temperature will increase by about 0.4-1.3oC by 2030 and by 0.9–4.0oC by 2070, and rainfall is projected to decrease (o10% by 2030 and 20–30% by 2070).

Southeast Asia as a tropic region in Asia suffered from a decline in rainfall as the number of rainy days decreased from 1960 to 2000 (Shadman et al., 2016). In Indonesia reported that the precipitation was declined (Zaki et al., 2021) and extreme hydrological events associated with drought have been more frequent and intense in the past 20 years in Indonesia which has 1,811 events in 2012, 1,961 events in 2014 and 2,372 events in 2017 (BNPB, 2017) with the potential risk as shown in Figure 1. In addition, the strongest El Nino of the last century, according to the National Oceanic and Atmospheric Administration (NOAA), occurred from 1997 to 1998 in Malaysia (Malaysia Meteorological Department, 2020).

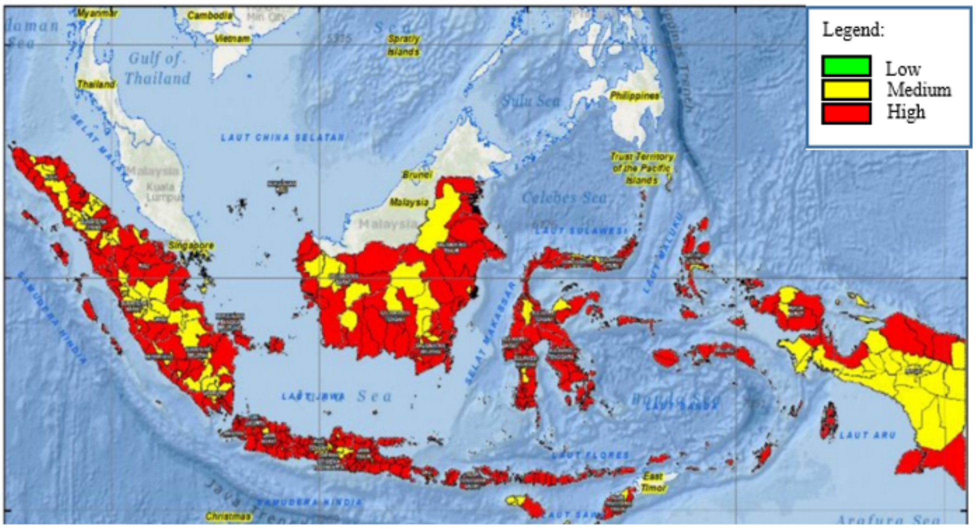


Figure 1. The potential risk of drought disaster in Indonesia.

Cambodia experiences frequent droughts, and widespread droughts occurred throughout the country in 1986–87, 1994, 1997–98, 2002, and 2005 (Ministry of Environment Cambodia, 2020), where the most severe climatic hazards in 17 out of 20 provinces of Cambodia. Laos PDR experienced moderate to severe droughts in the years 1961, 1966, 1971, 1978,1984, 1994, 1995, 1996, and 2009. Historical data recorded from 1966 to 2009 shows that Laos experiences an average of 1.5severe droughts every year (GFDRR, 2011). In Vietnam, extreme drought occurred extreme drought occurred simultaneously throughout the country in 1992–1993 and 2003–2004 (Stojanovic et al., 2020). Thailand is consistently confronted with the recurrent problem of annual drought due to the increase of mean annual temperature by 0.85°C and declining average annual rainfall, which has around 1989 -2013, 29 of 72 provinces were damaged by drought.

Spatially varied trends have been observed during the second half of the twentieth century, with increasing dryness particularly in Southeast Asia, adversely affecting socio-economic, agricultural, and environmental conditions as the consequences of green jobs in tropical climate Asia. In Thailand, the increased mean annual temperature and declining average annual rainfall has resulted in more frequent droughts over the past 20 years, and this resulted in reduction of rice (between 4 and 14%), which has the greatest damage caused by drought was in 2005 being THB 7565.9 million (approximately USD 220 million) and covering 71 provinces (Department of Disaster Prevention and Mitigation, 2015). In Mekong, droughts force farmers to plant crops that require less water and refrained from planting a second rice crop. Subsistence farmers have to see knew off-farm job and change their way of life because crops (rice, coffee, sugar etc.)

were damaged and stressed (Orn–uma Polpanich, Drought in Southeast Asia,2010). Also, in Cambodia, the drought of 2002 affected eight provinces and over two million people.

4. Drought adaptation strategies

The Intergovernmental Panel on Climate Change (IPCC) defines Adaptive capacity as the capability of a system to adjust successfully to climate variability and extremes to: (i) moderate potential damages; (ii) to take advantage of opportunities; and/or (iii) to cope with the consequences (IPCC, 2017). Adaptive capacity is the ability of a system and its components to absorb or recover from the impacts of extreme hydrological events. In any society, adaptation is the process through which people make themselves better able to cope with actual or expected climatic variation/natural hazards and it also helps to reduce overall vulnerability (Gandure et al., 2013).

Adaptation in any society denotes to initiatives and measures that are taken to lessen the vulnerability of natural and human systems against actual or expected climate change effects and to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Adaptation helps the people to protect their livelihood and, also strengthens any potential advantages it may bring. Based on negative impacts of drought, IPCC (2017) affirmed why adaptation is attaining importance in disaster risk management are: (i) Adaptation reduces the risk of any disaster and modifies environmental and human contexts that contribute to climate-related risk (Sagar, 2017). (ii) It also helps the people to prepare and respond to future disasters (Goldstein et al., 2019).

Emerging adaptations in agriculture to drought are diverse. In this study, we propose the drought adaptation strategies through three approaches are soft, hard, and sustainable adaptation Figure 2). Soft adaptation approaches include planning and de-risking processes, finance, knowledge generation and information flows, human resources development, and/or supply chain measures, as substantive yet physically intangible responses to climate impacts. Hard adaptation approaches encompass capital investments in technology or engineered infrastructure, including built structures. Sustainable adaptation which based on ecosystem includes management, conservation, and restoration of ecosystems as part of an overall adaptation strategy, something most societies are towards to achieve sustainable development goals are sustainable communities, climate action, and life on land , thus the need for new strategies (Galvin, 2021).

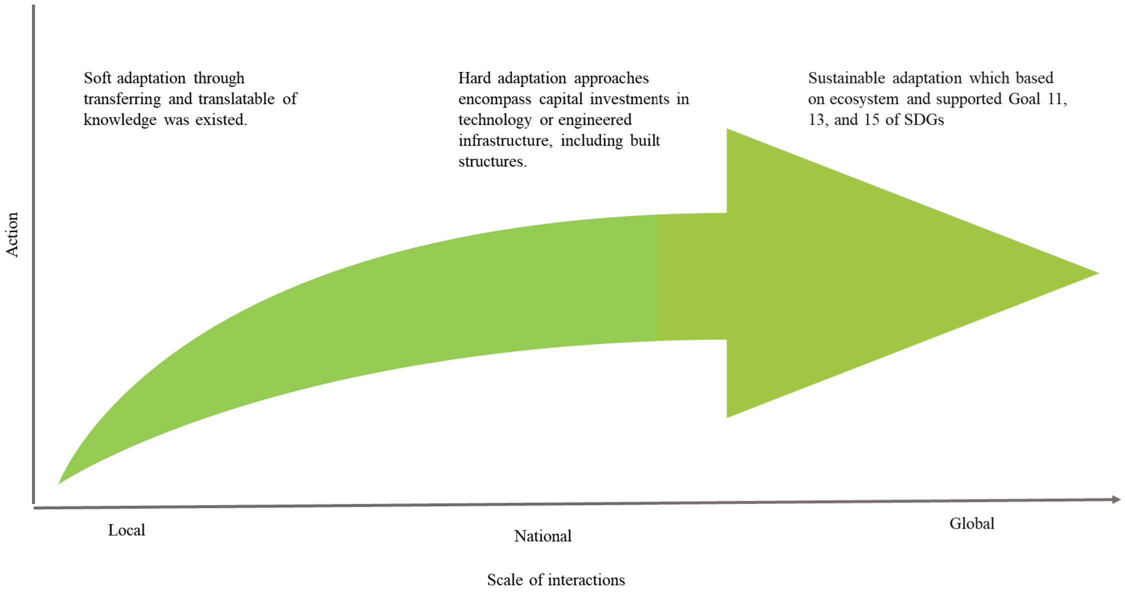


Figure 2. Farmer's adaptation strategies at scale of interaction and action to do.

5. The role of organic amendments to alleviate agricultural drought

According to Zaki et al. (2017), agricultural drought related to soil moisture which is characterized by a deficit of soil moisture. The condition leads to the limitedness for crop culture due to soil moisture availability is not enough for plant's needs. So, from above statement, this research aims to investigate the organic amendments including compost and rice husk ash to keep or increase soil moisture.

Compost is defined as stable aerobically decomposed organic matter (Paulin and O'Malley, 2008) and as the stabilized and sanitized product of composting (Insam and de Bertoldi, 2007). The product of the composting process which is a controlled decomposition process is resistant and includes complex organic materials (Thompson, 2007). This process is based on aerobic microbial breakdown which transforms organic materials into a variety of complex organic molecules (Paulin and O'Malley, 2008). Compost is usually dark brown and has an earthy appearance and smell (Thompson, 2007; Paulin and O'Malley, 2008).

Compost can be applied once or annually at the moderate application rates well adapted to sustainable agriculture (Mamo et al., 1999; 2000; Morlat, 2008). Compost application can increase soil water content at field capacity and permanent wilting point, and plant available water (PAW) (Celik et al., 2004; Curtis and Claassen, 2005; Taban and Naeini, 2006; Weber et al., 2007; Mylavarapu and Zinati, 2009). Compost can retain greater amounts of water at field capacity and permanent wilting point than mineral soils with a greater difference at field capacity than at permanent wilting point (Hudson, 1994; Olness and Archer, 2005).

Rice husks, wood remains, nut shells, manure, and crop residues are regarded as agricultural waste, but recently such solid wastes have been transformed into biochar for the purpose of carbon sequestration. Biochar is commonly defined as charred organic matter, produced with the intent of being deliberately added to soil to improve its agronomic properties. On average, one ton of dry biomass can create 400 kg of biochar containing 80 to 90% pure carbon (Lehmann et al., 2009) at 300 to 700 ºC, under low (preferably zero) oxygen concentrations. Rice husk contains a high content of silicon and potassium, nutrients which have great potential for amending the soil, while those with relatively higher carbon content (e.g. wood or nut shells) are currently used for the production of activated carbon.

The use of rice straw and rice husks in the field has been practiced for some time (Ponamperuma, 1982). Research has shown that incorporation of rice straw and rice husks can significantly improve soil properties by decreasing soil bulk density, enhancing soil pH, adding organic carbon, increasing available nutrients and removing heavy metals from the system, ultimately increasing crop yields (Williams et al., 1972). Similar studies on cowpea, soybean, and maize (Yamato et al., 2006) have also supported the application of biochar as a way to increase crop yields. Asia, a principal rice-growing region, has abundant rice residues, estimated at about 560 million tons of rice straw and 112 million tons of rice husks, respectively. These residues could be a valuable resource for the production of biochar to increase soil fertility. The effects of the addition of bio-natural resources may vary from soil to soil. However, the following effects have been seen in experiments: a) the rice husk charcoal increases the soil pH, thereby increasing available phosphorus (P), b) improved aeration in the crop root zone, c) improved soil water holding capacity and d) increased levels of exchangeable potassium (K) and magnesium (Mg) .

6. Local-indigenous knowledge for disaster risk reduction

Traditional knowledge is often described as knowledge which is “passed on within a community as part of its cultural heritage”, while science is assumed to be a “continuous testing, refutation or confirmation, and improvement of knowledge” (Lejeno et al., 2013). Other notable differences between the two is that traditional knowledge is regarded as a sort of a collectively spoken and articulated narrative that is shared by everyone in a community (Lejeno et al., 2013), while science is something which is pronounced only by experts and communicated to the public. Traditional/indigenous and modern/scientific knowledge are both valid resources of knowing and should be seen as complementary (Berkes, 2008) rather than competing and mutually exclusive (Lyotard, 1979). While science is focused on making logical deductions- or the search on general/causal but falsifiable explanation (Popper, 1959), traditional or indigenous knowledge seeks to understand the meaning of experience (Sandelowski, 1991). Although there exists no clear-cut definition, various efforts have been made to describe the concept of local-indigenous knowledge (Sin and Mansson, 2017).

Based on the United Nation’s Educational, Cultural, and Scientific Organization’s (UNESCO) program on Local and Indigenous Knowledge Systems (LINKS), local and indigenous knowledge refers to the “understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings” (Hiwasaki et al., 2014). As noted by Sin & Månsson [18]; the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) defines indigenous and local knowledge as “the multi-faceted arrays of knowledge, know-how, practices and representations that guide societies in their innumerable interactions with their natural surroundings” (MoSTE, 2015). To combine definitions found in relevant literature, local and indigenous knowledge is understood in this study as ‘a body of different types of knowledge and practices of societies accumulated through a continuous interaction with their natural surroundings’ (Fernando, 2003). Indigenous knowledge is formed and attained locally but is also dynamic in nature, repetitively influenced by both the users’ internal inventiveness and research, and by interaction with external systems (Flavier, 1995). Apart from being dynamic and adaptive, indigenous knowledge is constantly changing while retaining cultural identity.

The interactions between people, communities and places have given rise to a range of knowledge systems that are both traditional and adaptive (ICSU, 2002; Berkes, 2012). One of the core elements of the concept lies in the continuity and succession of such knowledge and practice that evolves over time, acquired through years of experiences of local people and passed on from generation to generation. Another feature of local-indigenous knowledge is that it is often gendered (Berkes, 1999). Although men and women share knowledge, they also hold different sets of knowledge vis-ȧ-vis the roles established by society (Nakashima et al., 2012). As noted by Rocheleau (1991), “half or more of indigenous ecological science has been obscured by the prevailing ‘invisibility’ of women, their works, their interests and especially their knowledge”.

There is a growing recognition by scholars that local-indigenous knowledge can make important contributions to both understanding and managing environmental change (Agrawal, 1995; Merrer et al., 2007; Walshe and Nunn, 2012). Local-indigenous knowledge and practices have been documented to play a vital role in biodiversity conservation (Kosoe et al., 2019), forest and wildlife conservation (Mavhura et al., 2019), flood prevention and management (Mavhura et al., 2013; 2017), climate change and adaptation (Savo et al., 2016; Mugambiwa et al., 2018; Manrique et al., 2018), and the study of environmental change (Berkes, 2009; Savo et al., 2014). It also serves a significant role in the development of early warning system for malaria (Macherera et al., 2016), and weather forecasting (Kalanda-Joshua et al., 2011). In the study and practice of DRR, considerable evidence have been gathered in the past decades to argue that local-indigenous knowledge and practices play an important role in the improvement of disaster preparedness, response, and recovery. As aptly pointed by Sin & Månsson (2017); Melanesians attribute indigenous knowledge to their survival from tsunamis in 1999 in Vanuatu. Indigenous knowledge and strategies have also aided indigenous cultural communities which survived the earthquake and tsunami in the Indian Ocean in 2004 (Rugmanee, 2005). Ahmad et al. (2017) reported that indigenous architecture is adapted in Kashmir Valley to reduce seismic risk, while Mavhura et al. (2013) has shown how traditional knowledge offers the ground for resilience in relation to floods in Zimbabwe.

Local-indigenous knowledge, in the form of community narratives, is also important in the storage, communication, and activation of complex environmental information that may be helpful in the reduction of climate change impacts and disaster risk. At a global level, the role and significance of local-indigenous knowledge in disaster risk reduction and management (DRRM) is evidently acknowledged in the Sendai Framework for Disaster Risk Reduction (SFDRR 2015–2030). Under the SFDRR, the old approach to disaster management requires a fundamental change by moving its focus from response to mitigation and preventive activities, projects and programs (Paveglio et al., 2018)

III. MATERIALS AND METHODS

1. Overview of identifying the study area

We conducted our research on Jawa island, Indonesia (Figure 3). Jawa has a total population of 150 million and there are three ethnic groups: Betawi, Sundanese, and Javanese. It has an area of ~130,000 km2 , which is about 6.8% of the total land area of Indonesia (BPS, 2020). A field experiment was conducted in rainfed farmland in Gondangrejo District, Karanganyar Regency, Central Java, Indonesia (7°29^{o} S, 110°51^{o} E) during the dry season (between July 10 and November 12, 2018). An original manuscript from Mangkunegaran Palace in Surakarta, Jawa Tengah, Indonesia, was studied as a source of local knowledge. Scientific analyses were conducted in Indramayu (6^{o}21^{o} S, 108^{o}19^{o} E; Jawa Barat Province), Sukoharjo (7°40^{o} S, 110°49^{o} E; Jawa Tengah Province), Sleman (7^{o}42^{o} S, 110^{o}20^{o} E; Yogyakarta Province), and Ngawi (7^{o}24^{o} S, 111o25o E; Jawa Timur Province).

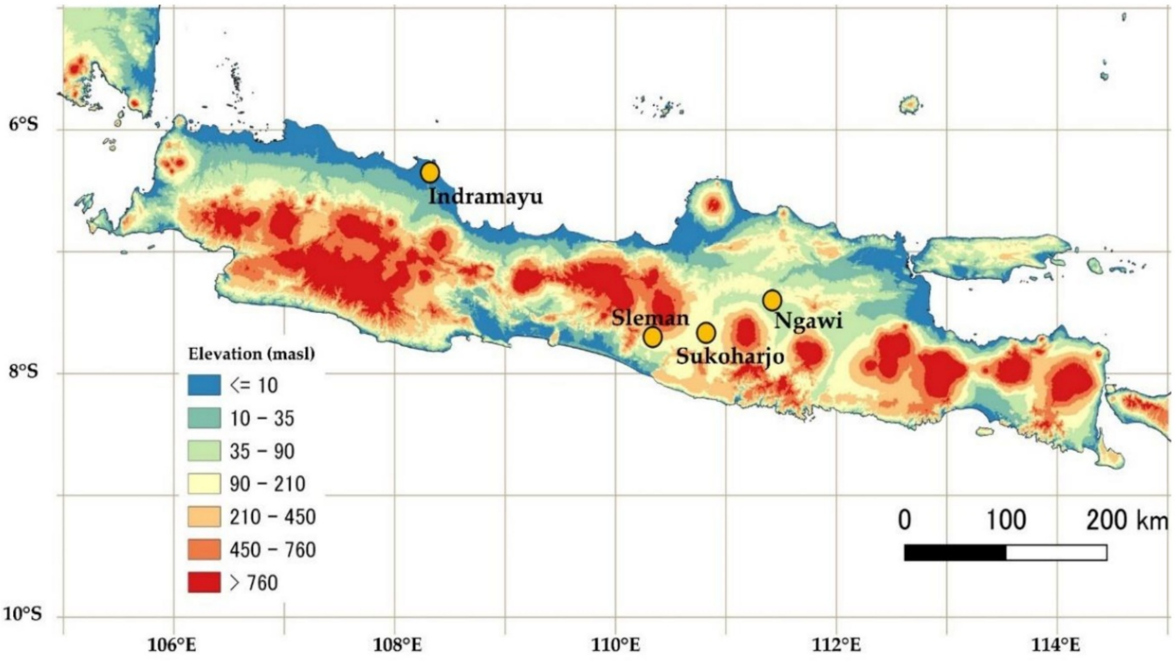


Figure 3. Map of study area in Jawa island, Indonesia

2. Organic amendments study experimental designs

A field experiment was conducted in rainfed farmland 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 4) 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 with no 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 and Marschner, 2013; Nguyen et al., 2013). In this study, SB was applied without any pre-treatment and the particle size was more than 5 mm. The water content was 40% for CP (Nguyen et al., 2013), 0% for RA, and 40–50% for SB (Teixeira 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 Rogovska et al.

(2011), at the time of land preparation (June 30, 2018) and after harvesting (November 15, 2018). An automatic weather system (AWS) was installed in the field to monitor precipitation, air temperature, and humidity; volumetric water content was monitored at 25 cm soil depth in each treatment plot by 5.5-cm soil moisture probes (EC-5; Decagon Devices, Inc., Pullman, WA, USA) placed horizontally. All sensors were linked to an Em5b data logger (Decagon Devices) and the data were recorded at 10-min intervals.

Figure 4. Photographs of the small farm reservoir (SFR) on (left) July 1, 2018, and (right) September 20, 2018.

3. Soil moisture and bulk density parameters

Agricultural drought is defined as a soil moisture deficit in farmland (Wilhemi and Wilhite, 2002). In this study, we assumed the effects of different organic amendments on water retention as the change of bulk and particle density, and converted the volumetric water content into the matric potential using the model of van Genuchten (1980) as follows:

$$\theta_\psi = \frac{\theta_s - \theta_r}{(1+ \alpha|\psi|^n)^m} + \theta_r \tag{1}$$

r and s are the soil water content at the matric potential ψ, the residual and saturated soil water content (m^3 m^{-3}); α parameter is considered to be equivalent to the reciprocal of the soil air entry value (kPa^{-1}); n is the shape parameter of the soil-water characteristic curve (SWCC) and set to 1.23 corresponding to the soil type of sandy clay (Moroizumi 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 parti- cle 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 r is close or equal to zero for a properly measured SWCC (van Genuchten et al., 1991, Tian et al., 2018). The parameters s and α were estimated following Rawls et al. (1982), and Mualem and Assouline (1989) and Assouline (2006), respectively, as follows:

$$\theta_s = 1 - \frac{\rho_b}{\rho_s} \tag{2}$$

$$\alpha = (\rho_b)^{-\omega} \tag{3}$$

where ω, ρb , and ρs are a constant coefficient (equal to 3.72), the bulk density (g cm^{-3}), and the particle density (g cm^{-3}), respectively.

4. Crop 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 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).

5. Analysis of local knowledge

Pranata Mangsa is written in the Javanese language of *Aksara Kromo*. Unfortunately, *Pranata Mangsa* has not been officially translated into other languages, and its applications remain limited. We translated *Pranata Mangsa* into Bahasa Indonesia, which has been recognized as an official language of Indonesia ever since the country gained independence, on 17 August 1945. We also translated it into English, as one of the official United Nations (UN) languages for international communication.

6. Analysis of scientific knowledge

Local knowledge was examined by scientific knowledge of the following hydro-meteorological events and systems.

a. Diurnal rainfall. We analyzed Tropical Rainfall Measuring Mission (TRMM) precipitation data, which is collected by the National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration (JAXA). The TRMM produces global precipitation estimates based on remotely sensed data. The daily 3B42 product (TRMM Multi-Satellite Precipitation Analysis, version 7) used in this study is available at https://giovanni.gsfc.nasa.gov/giovanni. Data for the period 1998–2015 (18 years), with spatial and temporal resolutions of 0.25° and 3 h, respectively, were analyzed.

b. Extreme events. We used the standardized precipitation index (SPI), which employs the gamma function to assess the likelihood of floods and drought based on the probability distribution of long-term precipitation (McKee et al., 1993). The SPI is defined as follows:

$$SPI = \frac{x_{i} - \bar{x}}{\sigma} \quad (4)$$

where, x_i is a specific period (e.g., monthly, annual) rainfall during the year i, x, and σ are the long term mean and standard deviation in the specific period. Floods and drought were identified using the SPI scale, as shown in Table 2. Positive and negative SPI values indicates that precipitation is above and below average, respectively (World Meteorological Organization, 2020). We calculated SPI values based on monthly precipitation using the 18 years precipitation of TRMM.

Table 2. The classification on standardized precipitation index (SPI) indices.

SPI values	Classification
≥ 2	Extremely floods
1.50 to 1.99	Severe floods
1.00 to 1.49	Moderate floods
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
≤ -2	Extreme drought

c. Farming system. We consulted previous studies to obtain data on crop patterns, fertilization, and water management.

7. Scientific view of local knowledge and adaptation strategies

The Local and Indigenous Knowledge Systems (LINKS) is a UNESCO interdisciplinary initiative that works: (1) to secure an active and equitable role for local communities in resource management; (2) to strengthen knowledge transmission across and within generations; (3) to explore pathways to balance community-based knowledge with global knowledge in formal and nonformal education; (4) to support the meaningful inclusion of local and indigenous knowledge in biodiversity conservation and management, and climate change assessment and adaptation. We adopted LINKS (Figure 5) to examine the components of *Pranata Mangsa*: crop calendar, crop pattern, and farming system; these domains were classified into four LINKS categories:

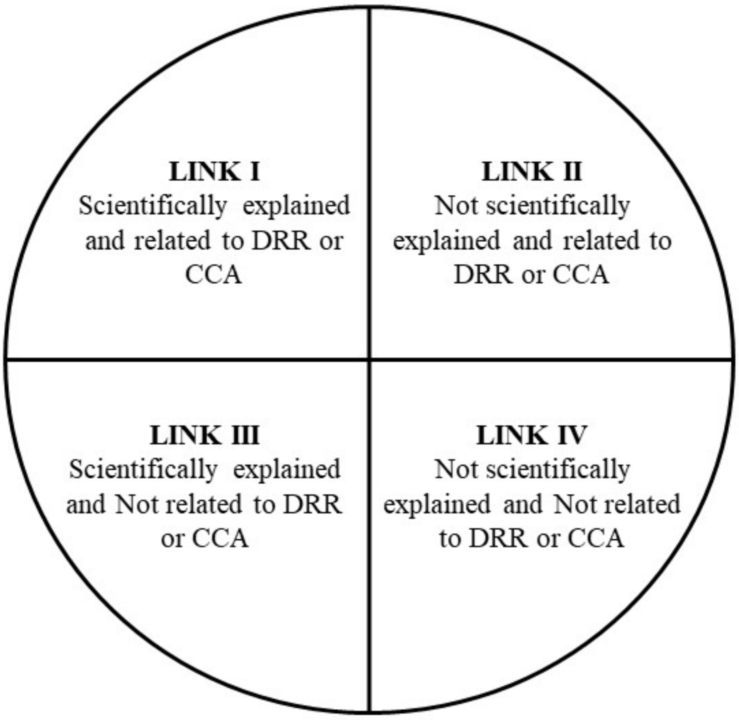


Figure 5. LINK categorization for integrating the local knowledge into scientific knowledge and related to DRR and CCA.

LINKS Category I: types of local and indigenous knowledge in this category include: (a) observations of celestial bodies (e.g., the moon, sun, and stars), which could help communities predict hazards; (b) environmental observations, such as of the direction and strength of winds; color, formation, and location of clouds; plants; and animal behavior; (c) materials used by local people for disaster mitigation, preparedness, responses, and recovery (e.g., for houses, as well as food eaten during periods of food scarcity); (d) environmental regulations, which play a major role in preventing and mitigating hazards such as coastal erosion, landslides, and floods (e.g., *Tara Bandu*, practiced in Timor-Leste, which governs social relations and places restrictions on the use of natural resources).

LINKS Category II: this category includes faith-based beliefs, and traditional rituals, legends, and songs. These phenomena cannot be explained in scientific terms, but are practiced by communities to improve resilience and “inner strength”. Thus, it is necessary to maintain these practices across generations. Faith-based beliefs and practices have been reported by many disaster survivors to improve community resilience, strengthen their will, and enable them to move forward. Such comments were made repeatedly by survivors of Typhoon Haiyan/Yolanda, which, struck the Philippines in November 2013.

LINKS category III: this category includes local and indigenous knowledge related to climate change and disaster prediction that cannot be understood from a scientific perspective. For example, people in Rapu-rapu island, Philippines, believe that a typhoon will occur when fish keep on moving with no rest, but researchers reported that the sign is not related to meteorological elements and as a behavior of fish for mating or food searching.

LINKS category IV: this category includes beliefs with no scientific basis that cannot be used for weather or disaster prediction. *Aneuk jame* which is a local knowledge in the coastal area of Aceh, Indonesia, has a belief that a hazard or disaster will occur when dogs howl loudly. This sign has no scientific evidence and is not related to the disaster.

IV. RESULTS AND DISCUSSION

1. 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 (BMKG, 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. The meteorological drought conditions ended on 120 DAP with 99.6 mm rainfall, after two small rainfalls events on 71 DAP (17.4 mm) and 108 DAP (15.2 mm) (Figure 6).

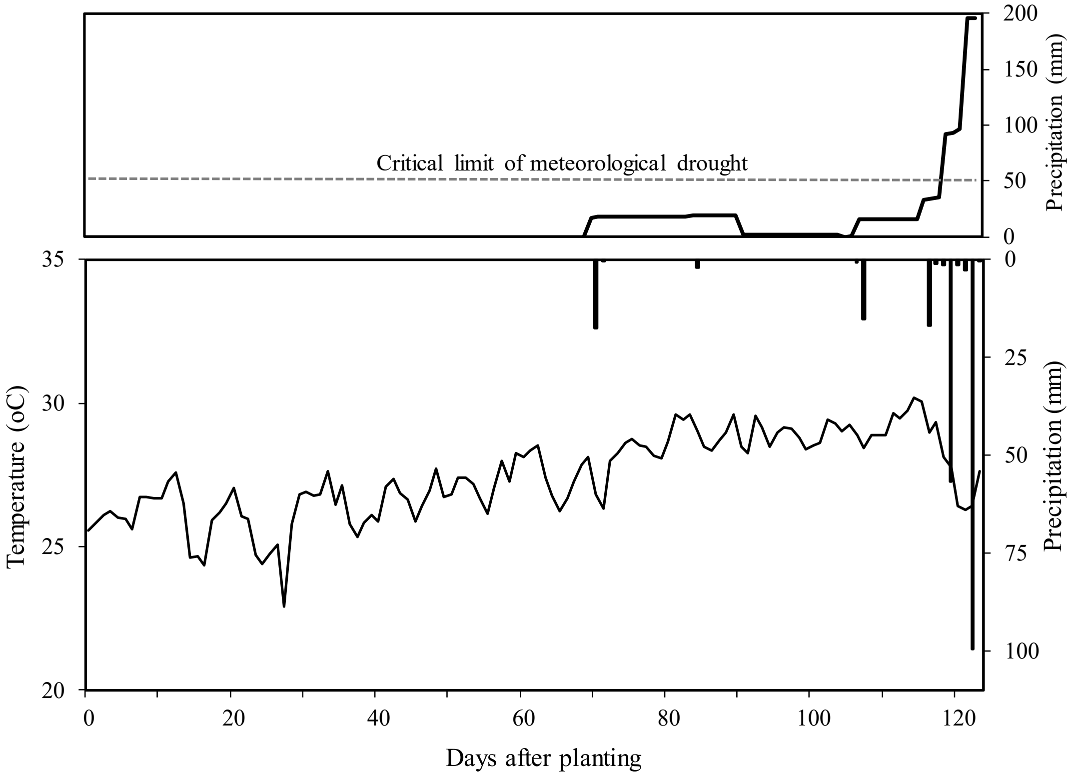


Figure 6. Precipitation and temperature condition in the experimental period.

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 affected on decreases of 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 7). The average and lowest soil moisture values were pF0.77 and pF0.88 under CP, pF 0.88 and pF1.01 under RA, pF 1.50 and pF1.91 under SB and pF1.04, and pF1.30 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.

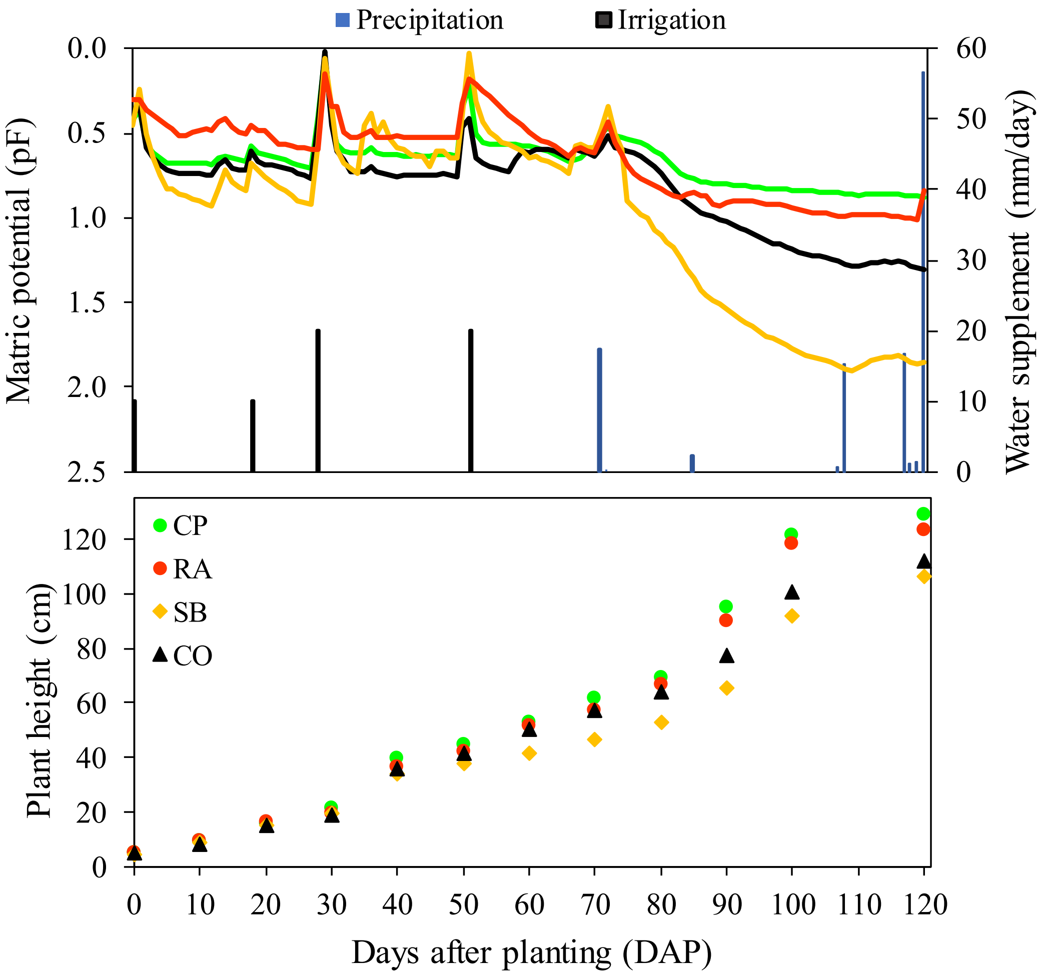


Figure 7. Time series of water supplementation, soil moisture conditions, and height

3. Maize growth responses under agricultural drought

Plant height was similar among all treatments until 40 DAP (Figure 7). 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 8); 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.

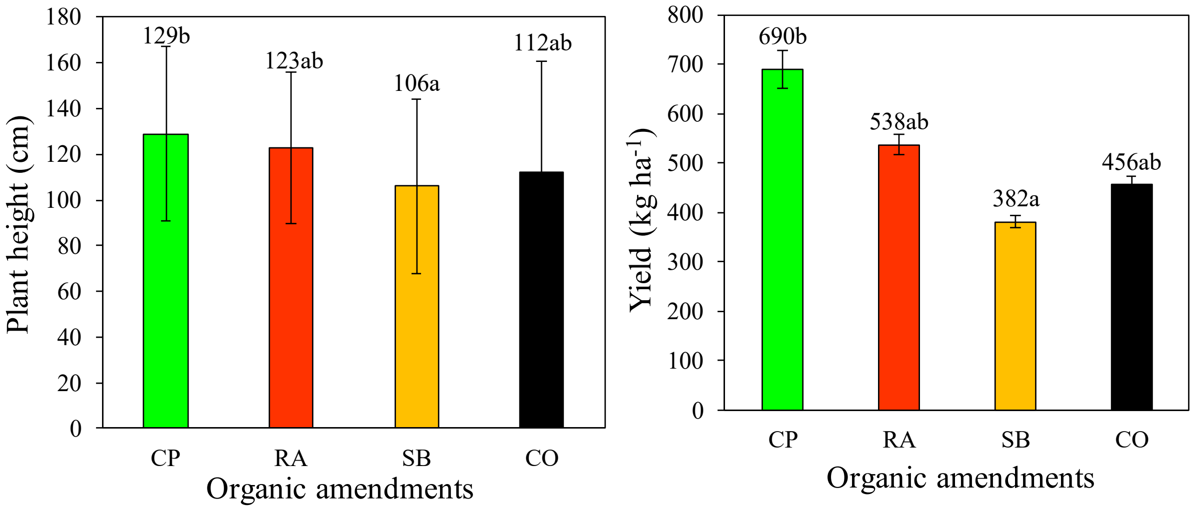


Figure 8. The effects of soil organic amendments on (a) plant height and (b) yield. Each value is represented by the mean ± SD. Values with different superscripts are significantly different at the 95% confidence level by Tukey test.

4. *Pranata Mangsa*: an overview

In what we term “the kingdom era”, Javanese society had four social classes: *Brahmana* (religious leaders), *Ksatria* (soldiers), *Waisya* (peasants), and Sudra (businessmen). The peasants were agrarian people who adhered to the “*Hamemayu Hayuning Bawana*” social philosophy, which focuses on creating a harmonious world through sustainable and environmentally friendly practices [28]. Javanese society in the kingdom era, i.e., from the Majapahit (700 AD) to the Mataram (1855 AD) kingdom, established local knowledge on water management and agricultural systems. King Mpu Sendok (929 AD) proposed the creation of many small farm reservoirs around the Brantas River (320 km length) in Jawa Timur and Bengawan River (600 km length) in Jawa Tengah. On 22 June 1855, King Sri Susuhunan Pakubuwono VII introduced the practice of using *Pranata Mangsa* as a crop calendar, and as a basis for organizing agricultural activities. The words *Pranata* and *Mangsa* mean rule and season, respectively.

The crop calendar starts around the summer solstice (on 22 June). On initial inspection, *Pranata Mangsa* appears very complicated and confusing because the number of days in each month varies from 23 to 43, as shown in Figure 9; this shape is based on the library of Mangkunegaran palace, which visualizes the *Pranata Mangsa* calendar. However, more careful examination revealed that the calendar is based on local cosmology. *Pranata Mangsa* has 12 months*: Kasa, Karo, Katelu, Kapat, Kalima, Kanem, Kapitu, Kawolu, Kasanga, Kadhasa, Sadha,* and *Dhesta*. The first 6 months have 41, 23, 24, 25, 27, and 43 days, respectively. The sequence is reversed in the latter 6 months, except for the 8th month, which has 26 rather than 27 days in normal years (*Wuntu*; it has

27 days in leap years (*Wastu*)). This local knowledge guides peasants to plan their activities in accordance with the seasonal cycle (Table 3).

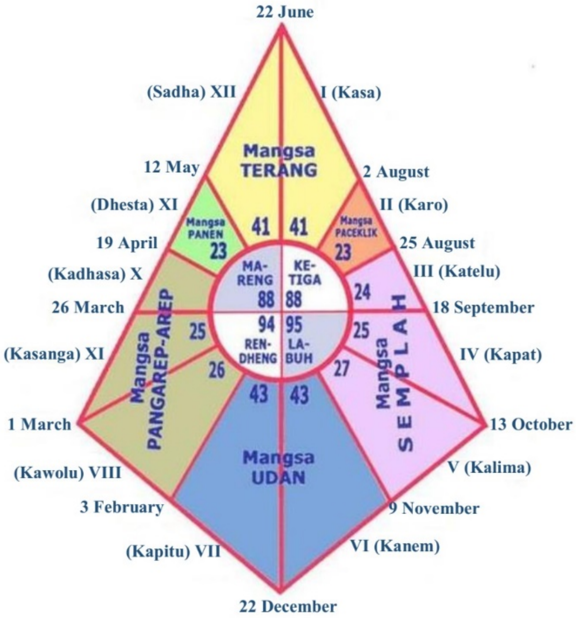


Figure 9. *Pranata Mangsa* in the Gregorian calendar. The numbers represent the numbers of days in the seasons and months, respectively.

Pranata Mangsa has a unique climate classification system: Javanese peasants use *Titen* to understand the progression of the seasons. *Titen* refers to the understanding, skills, and philosophies of Javanese peasants, accrued through their long history of interaction with the bioclimate. Together with other environmental factors, the bioclimate is crucial to the existence, growth, reproduction, and distribution of living organisms (Shul'gin, 1960). The bioclimates of various organisms have been well documented (Yoshino, 2009).

Table 3. Description of the *Pranata Mangsa* system on each *Mangsa*.

No	Months	Seasons	Timeseries	Bio-climatological signs	Farmer activities
1	*Kasa*	*Ketiga – Terang* (peak dry season)	22 June – 1 Aug. (41 days)	leaves fall down; grasshopper goes into the ground; high temperature	*Bero* or fallow land; Time to burn rice straw
2	*Karo*	*Ketiga – Paceklik* (dry season)	2 – 24 August (23 days)	Kapok tree (*Ceiba pentandra*) has flowering	*Bero* or fallow land;
3	*Katelu*	*Ketiga – Semplah* (last dry season)	25 Aug. – 18 Sept. (24 days)	Bamboo sprouts were growing	*Palawija* or secondary crop cultivating
4	*Kapat*	*Labuh – Semplah* (early rainy season)	19 Sept. – 13 Oct. (25 days)	*Kapok* was fruit development, Birds egging or hatchlings	*Palawija* harvesting
5	*Kalima*	*Labuh – Semplah* (rainy season)	14 Oct. – 9 Nov. (27 days)	Rainfall comes to the earth	Rice seedling on the tray
6	*Kanem*	*Labuh – Udan* (rainy season)	10 Nov. – 22 Dec. (43 days)	Fruit trees become mature with a small fruit	Land preparation on Paddy field
7	*Kapitu*	*Rendheng – Udan* (peak rainy season)	23 Dec. – 3 Feb. (43 days)	High precipitation, and flooding in a river	Rice transplanting to the field
8	*Kawolu*	*Rendheng - Pangarep- arep* (rainy season)	4 – 28/29 February (26/27 days)	Cats reproduction time	Fertigation on paddy vegetative phase
9	*Kasanga*	*Rendheng - Pangarep-arep* (last rainy season)	1 – 25 March (25 days)	*Cicididae* has sounded in nature	Paddy on reproductive phase
10	*Kadhasa*	*Marèng - Pangarep-arep* (last rainy season and no precipitation)	26 Mar. – 18 Apr. (24 days)	*Walang sangit* or rice ear bug (*Leptocorisa oratorius* Fabricius.) attack to paddy field	Paddy on ripening phase
11	*Dhesta*	*Marèng – Panèn* (Transitional season)	19 Apr. – 11 May (23 days)	Kapok fruit has mature	Paddy harvesting
12	*Sadha*	*Marèng – Terang* (early dry season)	12 May – 21 June (41 days)	*Tumpengan*	Harvest ceremony

Based on bioclimatological parameters, *Pranata Mangsa* distinguishes among four climatic seasons, as follows:

a. *Katiga*, which is also called the dry season, begins when leaves start to fall (*Sesotya murcå ing embanan*), the soil becomes cracked (*Bantålå rengkå*), and bamboo buds appear (*Sutå manut ing båpå*). *Sate sumber* is the peak of the dry season. *Katiga* has a duration of 88 days and occurs during *Kasa, Karo*, and *Katelu*.
b. *Labuh*, which can be translated as "shifting seasons" (dry to rainy), is considered to begin when the bioclimate induces a feeling of "peace in the heart" (*Waspå kumembeng jroning kalbu*). The arrival of rainfall (*Pancuran mas sumawur ing jagad*) leads to a "holy feeling" associated with the green color of plants (*Råså mulyå kasuciyan*). Labuh has a duration of 95 days and occurs during *Kapat, Kalima,* and *Kanem*.
c. *Rendheng*, or rainy season, begins when pests and diseases are carried by the wind (*Wiså kéntir ing marutå*). Other signs of this season include cats mating (*Anjrah jroning kayun*) and *Garengpung*, which is an appealing sound made by a species of Cicadidae (*Wedharing wacånå mulyå*) as shown Figure 10 (upper). *Rendheng* has a duration of 94 days and occurs during *Kapitu, Kawolu*, and *Kasanga*.
d. *Mareng*, which like *Labuh* also refers to "shifting seasons" (from rainy to dry), begins during the "animal gestation period" (*Gedhong mineb jroning kalbu*), which can also be translated as "flowering time" (e.g., for Kapok trees [*Sesotyå sinåråwèdi*]) as shown Figure 10 (bottom). Spring water dries up during this period (*Tirtå sah saking sasånå*). *Mareng* has a duration of 88 days and occurs during *Kadhasa, Dhesta*, and *Sadha*.

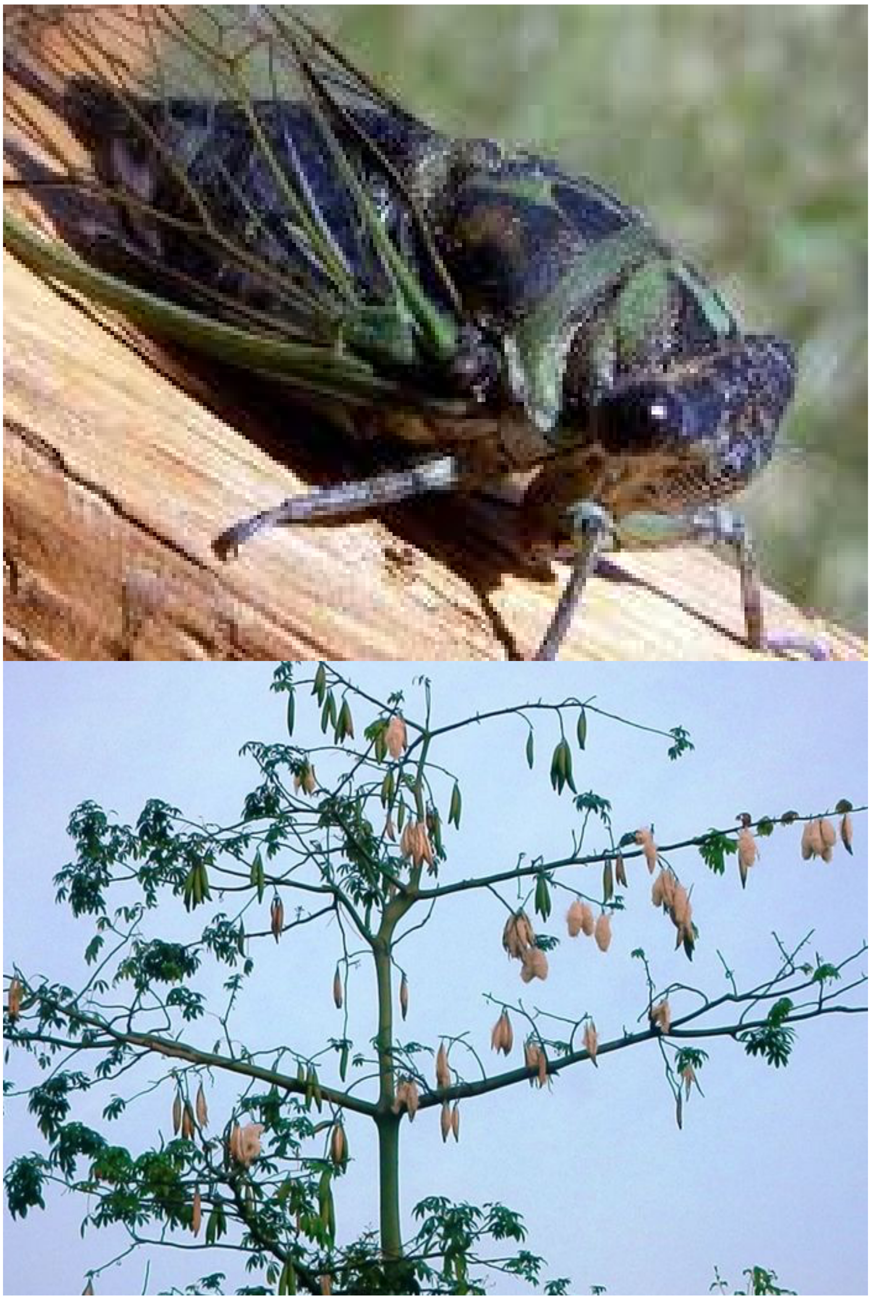


Figure 10. Natural signs of *Pranata Mangsa*: *Garengpung* or *Cicadidae* as a natural sign for the end of rainy season and ends the rainy season (upper); *Kapok* trees (*Ceiba pentandra*) as a natural sign for the end of dry season and beginning rainy season (bottom); (Source: Wikipedia.id)

Pranata Mangsa informed the organization of the farming system used by Javanese peasants, including crop patterns, irrigation, and field activities. The farming season starts on *Kasa* (22 June). The crop pattern for a given year is referred to as Berå-Palawija-Paddy, which is described in more detail below.

a. *Kasa* and *Karo* are months characterized by *paceklik* (food scarcity) and a lack of precipitation, which leads to rapid depletion of the water supply provided by small farm reservoirs in rainfed land. Berå means "take a rest". This concept is applied to the land itself; i.e., no planting activities occur in the fields. The farmer's activities at this time are as follows: (1) burning rice husk and straw from the previous harvest; and (2) praying to God to make it rain, in a ritual known as *Istisqa*.
b. *Katelu* and *Kapat* correspond to the end of the dry season and the early part of the rainy season, respectively. In these months, Javanese peasants begin to cultivate *Palawija*, i.e., a secondary crop (e.g., maize, soybean, and peanuts), to alleviate food scarcity.
c. *Kalima* is a month in which farmers come to the field to pray to God, and express gratitude for any rainfall in a ritual called *Seren taun* as shown Figure 11.
d. *Kanem* to *Kadhasa* are characterized by rice planting, land preparation, and water and pest management. For water management, the *macak–macak* system is used, which is characterized by intermittent flooding irrigation. Pest management involves planting refugia plants and placing *Sesajen* in the field.
e. *Dhesta* and *Sadha* are special months for Javanese farmers. These months coincide with harvest time and a ceremony called *Gulungan*, in which farmers bring their

agricultural products to a public area and eat and sing together to express their happiness and gratitude to God as shown Figure12.

Figure 11. The ceremony of *Seren Taun.* (Source: Kuningan.kab.go.id)

Figure 12. The ceremony of *Gulungan* or *Selamatan* after harvesting (a) and yield of harvesting from the fields arranged in pyramids, it called *Gunungan*. (Surakarta.go.id)

5. Extreme events

Precipitation is a crucial component of the water cycle (Trenberth et al., 2003), and is the variable most strongly associated with atmospheric circulation in weather and climate studies (Kidd and Huffman, 2011). Analysis of rainfall data showed that the total annual precipitation is 2233, 2396, 2702, and 2937 mm year−1 for Indramayu, Ngawi, Sleman, and Sukoharjo, respectively. Figure 13 shows that the average precipitation amount in *Kasa, Karo*, and *Katelu* is below 100 mm day^{-1}, with the lowest amount being just 12.63 mm day^{-1} (in *Karo*, Indramayu). The highest rainfall amount was recorded in *Kapitu*, Sukoharjo, at 601.16 mm day^{-1}.

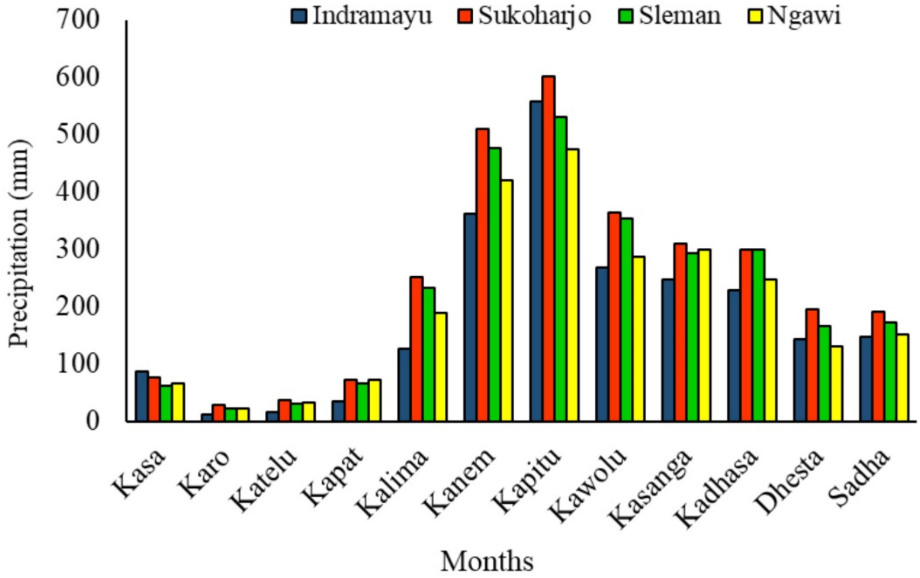
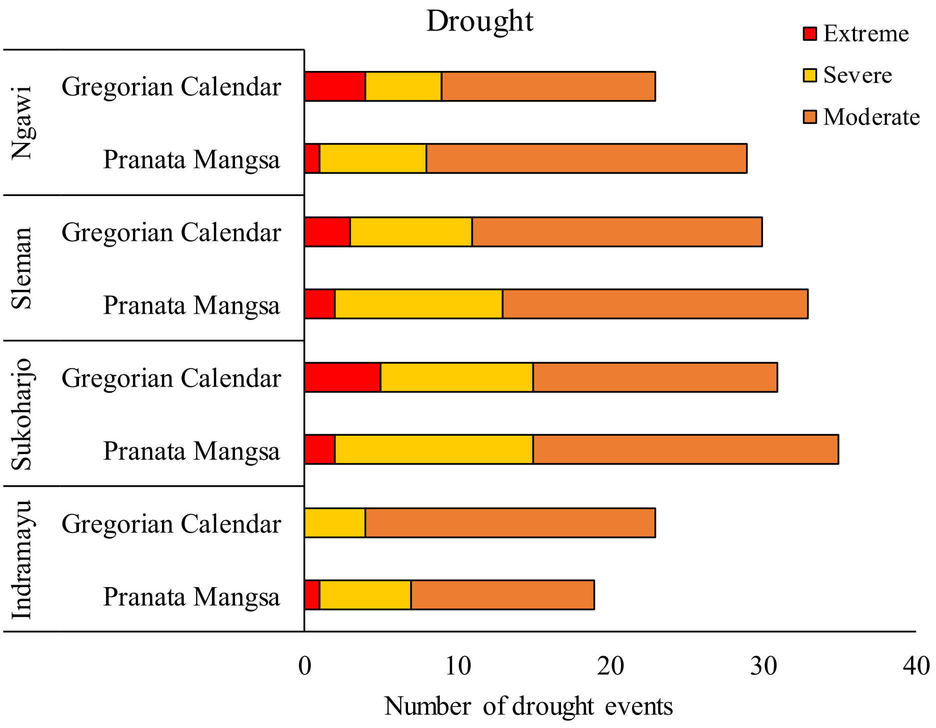


Figure 13. The intensity of precipitation during 1998–2015.

Monitoring precipitation is crucial to the well-being of local residents; too much rainfall endangers life and property, while too little causes droughts that negatively impact agriculture and can lead to starvation. Hence, analysis of extreme precipitation events (e.g., drought and floods) is necessary. The SPI is recommended for assessing drought and floods. It has the following advantages: (i) only a single input variable (precipitation) is necessary, (ii) both wet and dry periods can be analyzed, (iii) analyses can be performed at different time scales, (iv) droughts and floods can be categorized, and (v) the probability-based structure can aid risk management and decision analysis (World Meteorological Organization, 2020).

In this study, the SPI was used at the 1-month time scale to identify drought and floods, informed by *Pranata Mangsa* and the Gregorian calendar, with the goal of successful adaptation to extreme events. The SPI is an index for extreme events comparing with the average and results in different values depending on the range of the specific period, even if the same precipitation data is adopted. During the observation period (1998–2015) both drought and flood occurred (in 1998 and 2010, respectively). Figure 14 (upper) illustrates the superiority of *Pranata Mangsa* over the Gregorian calendar for mitigating the effects of extreme drought events in all regions, except Indramayu. However, *Pranata Mangsa* was not useful for mitigating the effects of extreme floods, except in Sleman, as shown in Figure 14 (bottom). These results suggest that *Pranata Mangsa* has limitations in the size and location of the community; in line with the term of local knowledge, which is composed of understanding, skills, and philosophies developed by the local society with long histories of interaction with their natural surroundings.



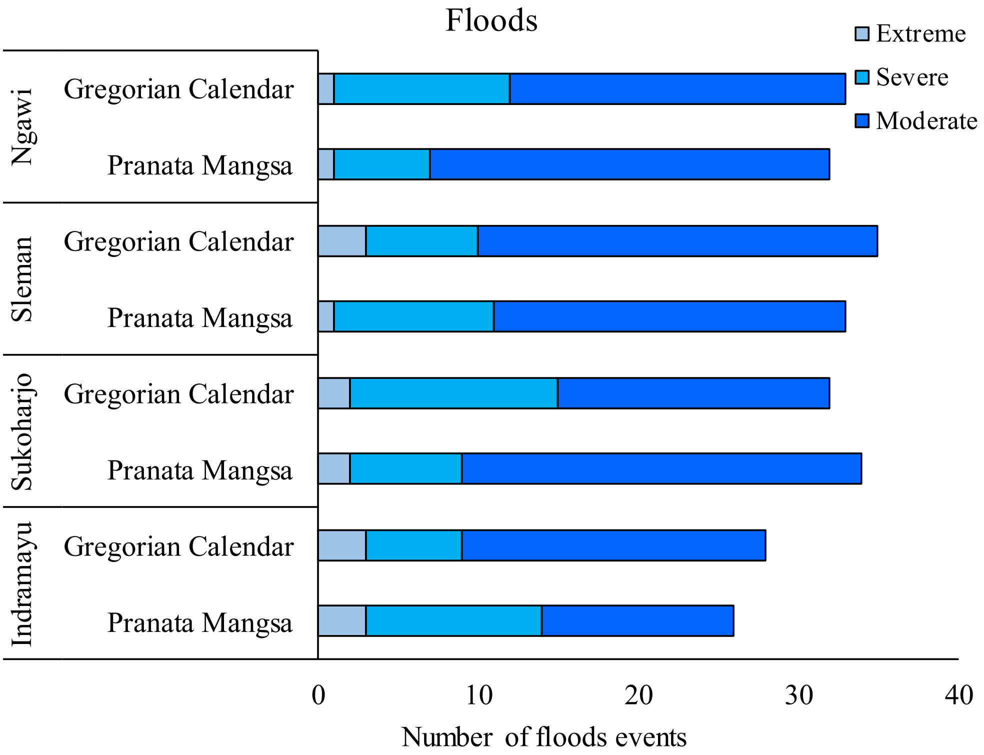


Figure 14. The severity levels and number of drought (upper) and floods (bottom).

6. LINKS: Integrating local and scientific knowledge

Previous studies have documented the effectiveness of LINKS for reframing local knowledge in scientific terms, for example to mitigate the effects of hydro-meteorological disasters in coastal areas. *Smong* was used in Aceh to strengthen communities following the tsunami disaster in 2004, while *Ai lulik* and *Fatuk lulik* were used to predict and prevent landslides in Timor Leste, and *Rapu-rapu* was used to predict typhoons in the Philippines (Hiwasaki et al., 2013). However, these studies did not comprehensively explain how local knowledge has been applied in the absence of scientific data, nor how to manage small areas affected by certain kinds of disasters using local knowledge. In this study, we applied LINKS to the agricultural system in Jawa, using *Pranata Mangsa* as a framework. Thus, local knowledge was used in association with scientific data (e.g., on diurnal rainfall and extreme hydrological events) to adapt to floods and drought conditions. We found that *Pranata Mangsa* can be interpreted using LINKS.

Our findings confirmed that local knowledge can be integrated with scientific data to increase the resilience of Javanese agricultural communities to floods and drought. Our initial analysis, LINKS I, showed that diurnal rainfall data accorded with the characteristics of, and transition among, seasons. *Sate sumber* refers to drought, which is concerning for farmers but can be well explained by empirical data. *Sate sumber* may occur during *Kasa*, *Karo*, and *Katelu* when the precipitation amount is below 50 mm day^{-1}. In response, the *Bera-Palawija* crop pattern was established in *Katiga* and *Labuh* based on *Pranata Mangsa*, and has reduced crop losses, improved soil quality, and increased soil moisture. In addition, farming activities are scheduled with water management (*Macak-macak*), soil recovery, and pest management in mind, thus, increasing the number of panicles and paddy yield in Indonesia (Nugroho, 2018), and reducing water consumption and methane emissions (Keiser et al., 2002). Also, Berå and the application of burnt rice husk (2 tons ha^{-1}) as an organic amendment can alleviate meteorological and agricultural drought through the "restland" concept. This can allow farmers to adapt to the effects of widely varying precipitation amounts (Nielsen et al., 2010), and will improve soil bulk density and porosity (Jeon et al., 2010). As discussed above, some aspects of *Pranata Mangsa* cannot be explained by, or integrated with, scientific data, but nevertheless have a significant effect on DRR and CCA (based on our second analysis, LINKS II).

Our analysis of local knowledge indicated that rituals and ceremonies promote respect for God and nature among Javanese peasants. As an example, *Istisqa* is a farming activity practiced when the dry season arrives, based on faith-based beliefs and designed to make communities more resilient. According to our LINK IV analysis, some components of *Pranata Mangsa* cannot be related to DRR or CCA, including *Sesajen*, which is the rituals to the God by placing some materials, including myrrh, fruit, and cigarettes at the side of the field for repelling pest or as a pest management as shown Figure 15. Our results showed that the components of the local knowledge were verified and validated by a scientific data approach, so as to inform policies supporting farming activities, and empower communities to make informed decisions regarding adaptation and DRR.

To our knowledge, this was the first study to investigate the effectiveness of LINKS for integrating local and scientific knowledge of agriculture to mitigate the effects of drought and floods. Our results indicated that *Pranata Mangsa* can be easily integrated with scientific data, enabling optimal strategies for DRR and CCA to be adopted by scientists, farmers, and policymakers. Although LINKS was successfully used to integrate *Pranata Mangsa* with scientific data, the applicability of this approach to other knowledge systems in Indonesia should be assessed in future work.

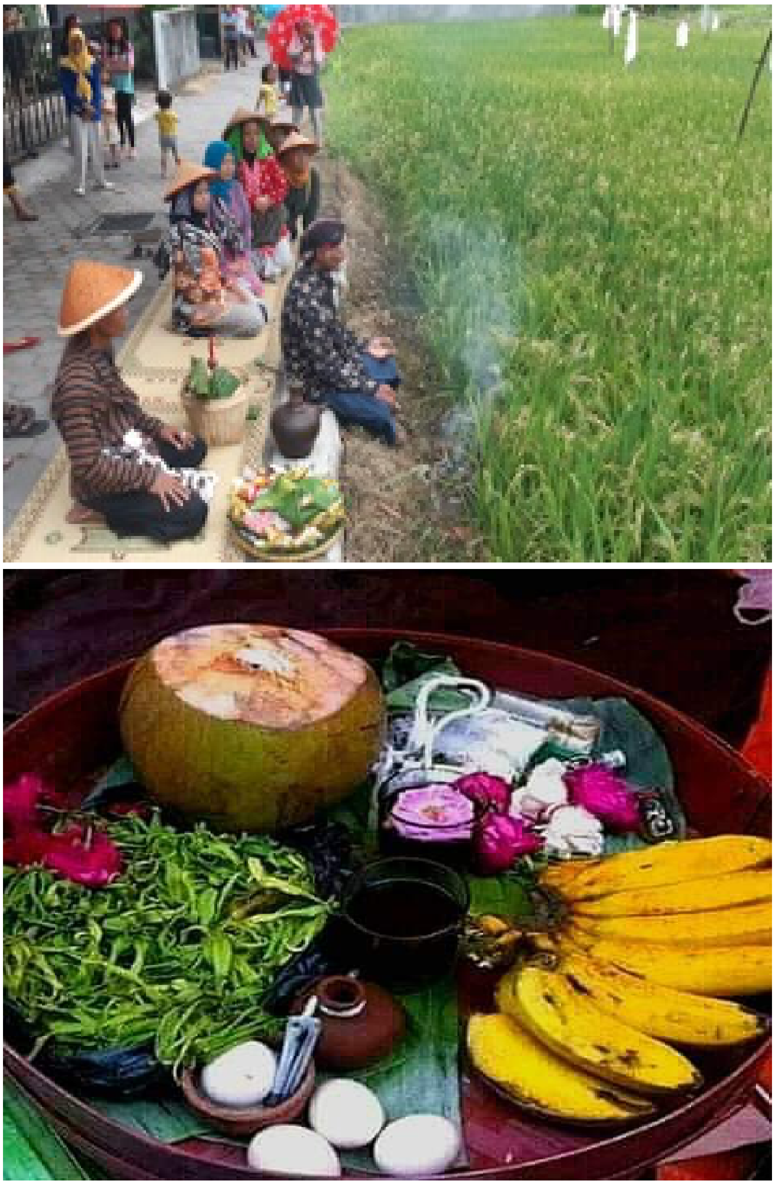


Figure 15. *Sesajen* placed for repelling pests.

V. CONCLUSION

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.

Pranata Mangsa is an important system of local agricultural knowledge used in Jawa, and includes information regarding climate conditions, crop patterns, and farming activities. All of these areas can be related to DRR and CCA based on scientific data. Rituals and ceremonies help communities build resilience, but cannot be explained in scientific terms. It is important to recognize that *Pranata Mangsa* is not wholly effective for DRR and CCA: there are limitations to its utility, depending on: (1) the size and location of the community; (2) the commitment of the participants, especially from the younger generation; and (3) support from stakeholders and policymakers concerned with adaptation to, and mitigation of the negative effects of, extreme hydrological events. In conclusion, this study successfully used LINKS to integrate local and scientific knowledge for flood and drought risk reduction and CCA, which should increase the resilience of communities.

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