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IMPLEMENTATION OF CLIMATE-SMART AGRICULTURE TO BOOST SUGARCANE PRODUCTIVITY IN INDONESIA

Implementasi Pertanian Cerdas Iklim untuk Meningkatkan Produktivitas Tebu di Indonesia

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ABSTRACT

Sugar is one of Indonesia's strategic commodities, but its production fluctuates over time and is still unable to comply with the national sugar demand. This condition may even get worst with climate change. Although climate-smart agriculture is a promising thing, it is basically a genuine concept for many farmers in Indonesia, including sugarcane growers. The paper briefly reviews and argues agronomic practices as a climate-smart agriculture approach adapted by sugarcane growers in Indonesia to increase its production under the changing climate. Some agronomic practices can be adopted by the Indonesian sugarcane growers as climate-smart agriculture, i.e., efficient irrigation, improved drainage of sugarcane plantations, the use of suitable sugarcane cultivars, green cane harvesting-trash blanketing, the amendment of soil organic matter, crop diversification, precision agriculture, and integrated pest management. From the Indonesian government's side, research should be propped as there is limited information about the effectiveness of each aforementioned agronomic intervention to alleviating the adverse effect of climate change and to improving sugarcane growth. Practically, to ensure the success of climate-smart agriculture implementation in the Indonesian sugar industry, multi-stakeholders, i.e., sugarcane growers, researchers, civil society, and policymakers, should be involved, and the government needs to link these stakeholders.

Keywords: Sugarcane, productivity, climate-smart agriculture, agronomic management, precision agriculture

ABSTRAK

Gula merupakan salah satu komoditas strategis Indonesia, namun produksinya mengalami fluktuasi dan belum dapat memenuhi kebutuhan gula nasional. Kondisi ini diperburuk oleh perubahan iklim. Pertanian cerdas iklim memberikan peluang besar bagi tanaman tebu untuk dapat beradaptasi dan memitigasi dampak perubahan iklim. Meskipun pertanian cerdas iklim menjanjikan, namun merupakan hal baru bagi banyak petani di Indonesia, termasuk petani tebu. Tulisan ini menelaah dan mengemukakan praktek agronomi sebagai pendekatan pertanian cerdas iklim yang dapat diterapkan petani tebu di Indonesia dengan tujuan meningkatkan produksi tebu di bawah kondisi perubahan iklim. Terdapat beberapa praktik agronomis sebagai bagian dari pertanian cerdas iklim yang dapat diadopsi petani tebu di Indonesia, seperti efisiensi irigasi, perbaikan sistem drainase, pemilihan kultivar tebu yang sesuai, pemanfaatan residu serasah tebu, peningkatan bahan organik tanah, diversifikasi tanaman, pertanian presisi, dan pengelolaan hama terpadu. Dari perspektif pemerintah Indonesia, penelitian harus didukung karena terbatasnya informasi efektivitas masing-masing intervensi agronomi tersebut untuk mengurangi dampak buruk perubahan iklim dan untuk meningkatkan pertumbuhan tebu. Secara praktis, untuk memastikan keberhasilan penerapan pertanian cerdas iklim pada industri gula Indonesia, multi-stakeholder yang terdiri atas petani tebu, peneliti, masyarakat sipil, dan pembuat kebijakan harus saling terlibat dan pemerintah perlu menghubungkan para pemangku kepentingan ini.

Kata kunci: *Tebu, produktivitas, pertanian cerdas iklim, manajemen agronomis, pertanian presisi*

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is one of the strategic estate crops in Indonesia. It is a major sugar producer and has a vital role in the national economy (Sulaiman *et al.* 2019). Sugarcane production in the country fluctuates over time, but the trend is decreasing (Putra et al. 2013; Indonesian Directorate General of Estate Crops 2017; Indonesian Ministry of Agriculture 2020). Sugarcane yield in Indonesia was started to increase to reach a level of 158 tons per hectare in 1972. In the epoch before Indonesia's Independence Day in 1945, cane sugar became one of the country's export materials. This feat can be associated with good agricultural practices (GAP) that sugarcane growers and sugar mills have intensively executed during that period. From time to time, sugar productivity is declining, reaching a low of 5.517 tons per hectare in 2011 (Indonesian Directorate General of Estate Crops 2019). Such decline may be associated with numerous factors, such as water availability, cultivars, cultivation practice, and sugar mill performance (Toharisman and Triantarti 2016). The decline may also be linked to climate change (Srivastava and Rai 2012; Chandiposha 2013; Toharisman and Triantarti 2016). The agricultural sector is in every way illustrious as one of the essential drivers of climate change, but at the same time, it is also susceptible to climate change.

Sugarcane is in most cases prone to climate change, although it can also be exceptionally adaptive (Srivastava and Rai 2012). Since sugarcane has a long growing season, and it remains in the soil throughout the year, its productivity can be supremely affected by climatic conditions (Srivastava and Rai 2012; Francisco *et al.* 2017). Globally, climate change may affect crop growth directly through increasing temperature and changing rainfall, or circumstantially through the soil, nutrient, rising pests and pathogens attack (Hussain *et al.* 2018). The adverse consequences of climate change on sugarcane production in developing countries, such as Indonesia, are expected to be greater due to low adaptive capacity, high vulnerability to natural hazards, poor forecasting systems, and poor mitigating strategies (Zhao and Li 2015). Extreme weather and climatic variability are amongst major problems in the Indonesian sugar industry (Toharisman and Triantarti 2016), which caused water stress conditions and the increase in temperature that may adversely affect sugarcane growth (Sonkar *et al.* 2020). In the end, this condition may increase the vulnerability of growers' households who are dependent on sugarcane farming for their livelihoods (Lipper *et al.* 2014). Even, the adverse effects of climate change on sugarcane production are likely to worsen after 2050, if the greenhouse gas (GHG) emissions are still abiding high (Zhao and Li 2015). Nevertheless, some research also reported positive impacts of climate change on sugarcane yield, which can be correlated with increased rainfall, temperature, and CO_2 (Baez-Gonzalez *et al.* 2018; Ruan *et al.* 2018).

Under the diminishing trend of sugarcane production in Indonesia, there is a higher national demand for sugar over time due to increased population and income. By far, the insufficiency of sugar production in Indonesia is compensated by imports. There is a need to increase national sugarcane production, so the dependency on imported sugar can be decreased. The current achievement of national sugar production is due more to the expansion of sugarcane plantations or the so-called extensification program (Soetopo 2014), especially outside Java islands. As Java island contributes to nearly 60% of national sugarcane production and there is often fierce competition of land uses between sugarcane (Dianpratiwi et al. 2018), and the other agricultural crops in Java island. Therefore, an intensification program needs to be taken into consideration. One of the intensification strategies to increase sugarcane productivity under climate change is climate-smart agriculture (CSA). CSA is an adaptation concept, which is generally applicable for all crops (FAO 2021). This concept focuses on the sustainability and resilience of the food and agricultural production system under climate change. CSA offers the opportunity to increase sugarcane yield while adapting and mitigating the climate change effect. CSA practices can enhance sugarcane in a range of 5-10% (Wekesa 2017). CSA implementation in sugarcane cultivation consists of soil and water management practices to support agronomic growth, emphasising water productivity and soil nutrient balance. Proper pest management, a green harvesting system, and soil organic improvement can support the sustainability of sugarcane production (Srivastava and Rai 2012).

The three primary pillars of CSA, i.e., sustainability, economic, as well as social and environmental dimensions, must be well integrated. Indonesian farmers can use the planning and implementation of CSA to cultivate all crops, including sugarcane. Sugarcane is known as a long-duration crop that requires several cultural and management operations from planting to harvesting (Shukla *et al.* 2019). The present paper collates CSA approaches, focusing on the agronomic factors to be implemented in Indonesian sugarcane plantations. This study's outcome can be used to inform sugarcane growers, sugar mills, the government, or the other sugar-related stakeholders in Indonesia as a consideration to increase sugarcane productivity under the changing climate conditions.

GENERAL CONCEPT AND PLAUSIBLE CLIMATE-SMART AGRICULTURE PRACTICES IN THE SUGARCANE FARMING

Management of climate risk in Indonesian agriculture is still lacking (Surmaini and Agus 2020). Thus, building resilience to climate change in agriculture is essential to ensure its sustainable production under uncertain climatic conditions (Nciizah and Wakindiki 2015; Lipper *et al.* 2018). The adverse effects of climate change on agriculture can be reduced by enhancing the adaptive capacity of growers and maximising resource use efficiency (Lipper *et al.* 2014; Lipper *et al.* 2018).

CSA is an approach to transform agricultural systems and to support food security under a changing climate, with the following focal aims: 1) increasing agricultural productivity in a sustainable way, 2) strengthening the adaptation of resilience of agricultural and food security systems towards climate change, and 3) lowering GHG emissions from agriculture (FAO 2013). It has been considered as a promising approach from the agriculture sector to deal with climate change in an integrated manner. CSA offers both mitigation and adaptation to climate changes through integrated soil-crop system management (Nciizah and Wakindiki 2015; Torquebiau *et al.* 2018). The difference between CSA and 'business-as-usual' approaches is that the CSA emphasises the implementation of flexible and context-specific solutions, supported by innovative policy and financing actions (Lipper *et al.* 2014; Lipper *et al.* 2018).

CSA approach is extensively promoted since the first time it was launched in 2009. CSA is basically unfamiliar for many farmers in Indonesia but has been implemented for some commodities, such as rice plants (Perdinan et al. 2018). However, the concept is not yet famous for sugarcane cultivation (FAO 2013). A range of CSA practices and technologies can be initiated as adaptation strategies for dealing with climate risks in sugarcane cultivation in Indonesia (Figure 1).

The choice of agronomic interventions in CSA should be well considered. This is because the three main pillars of the CSA, i.e., high productivity, resilience to climate change, and minimum GHG emission (FAO 2013), can be contradictive amongst them. For instance, increasing sugarcane production means that more fertiliser and other inputs are required, but at the same time, it leads to increased GHG in the atmosphere. The other example, such as increased mechanisation, can help to enhance sugarcane production, but it may lead to increased GHG emissions. In the following, we propose some agronomic practices, which are synergetic between the three CSA pillars without considerable trade-offs.

Efficient irrigation

Water is the most critical resource for global sustainable agriculture. Sugarcane is a 'thirsty' crop, as it can use up to around 20 megalitres of water per hectare (Shrivastava et al. 2011; Steduto et al. 2012). In Indonesia, sugarcane is primarily cultivated in drylands (Riajaya 2020), which relies on rainfall. Even, rainfed sugarcane lands in Indonesia account for 70-80% (Subiyakto 2016). There has been a dramatic shift in sugarcane farming from irrigated to drylands (Soetopo 2014). With the presence of climate change, rainfall is increasingly unpredictable. Some researchers observed that Indonesia consistently experiences dry season and drought during ENSO (El-Nino Southern Oscillation) cycles (Nugroho et al. 2013; Surmaini et al. 2015). Consequently, there is a change in the wet and dry spells and seasonal rainfall patterns (Prabhakar et al. 2013), which could be a severe threat to sugarcane production.

When soil condition is too dry, it is critical to irrigate sugarcane plantations. Irrigation is essential to boost

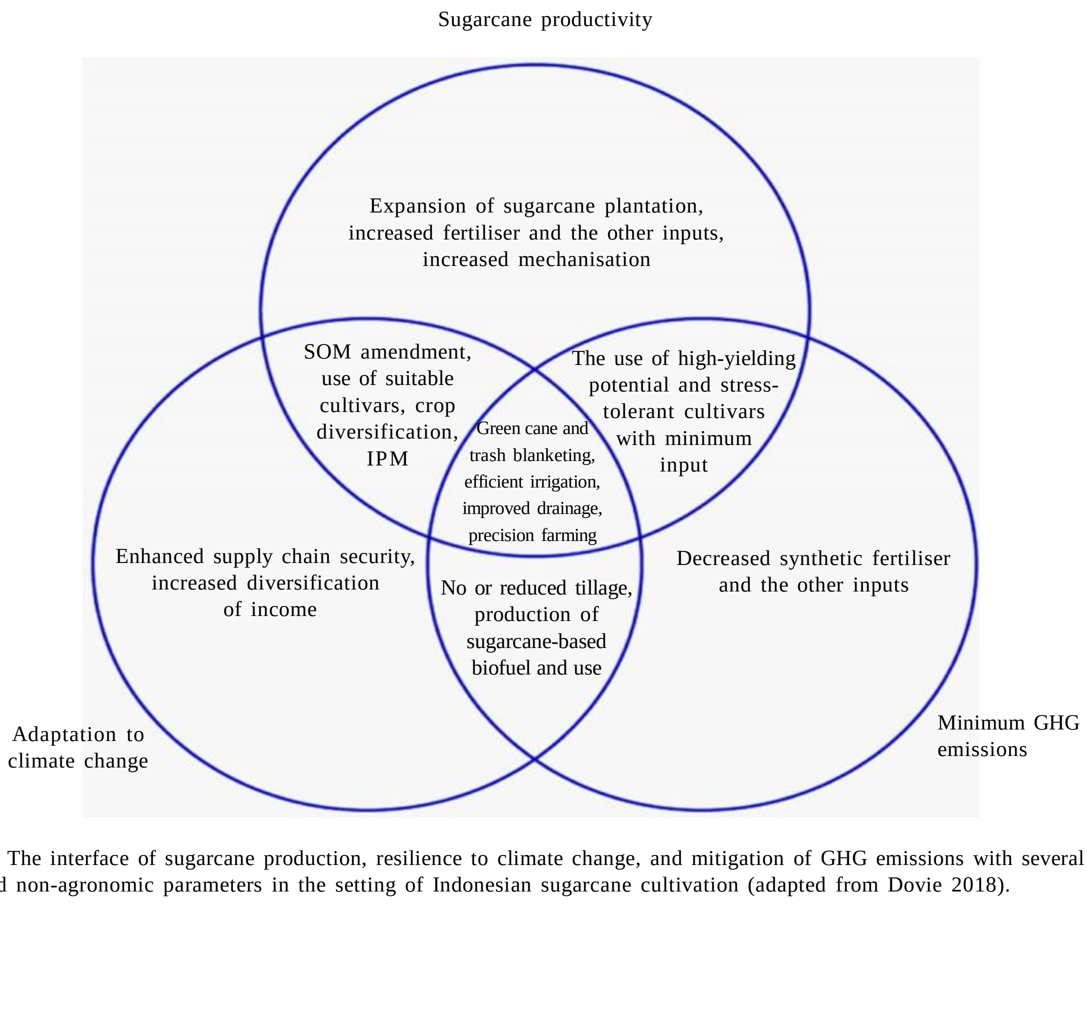

Figure 1. The interface of sugarcane production, resilience to climate change, and mitigation of GHG emissions with several agronomic and non-agronomic parameters in the setting of Indonesian sugarcane cultivation (adapted from Dovie 2018).

sugarcane production in dry areas (Silva et al. 2019). It is necessary to invest in irrigation infrastructures, such as building water reservoirs and providing pumps or pressurised irrigation systems (Sanghera et al. 2019). It is predicted that irrigated areas will rise in oncoming years, while freshwater supplies will be switched from agriculture to domestic use and industry. Irrigation efficiency in several sugarcane plantations using surface irrigation also usually very low since only less than 65% of the applied water is used by the crops (Steduto et al. 2012; Ranomahera and Ritzema 2020). Over-irrigation can lead to water-logging conditions for the crop, temporal water shortage to other farmers, increased pathogens, soil nutrients lost due to leaching or deep percolation, contamination of the aquifers from agrochemicals, reduction in crop yield and quality, as well as increased production cost (Chartzoulakis and Bertaki 2015). An efficient water use system is needed to adapt to the changing climate (Sonkar et al. 2020).

Some sustainable water management options to optimise water use and water use efficiency are localised irrigation, sub-surface drip irrigation, sprinkler systems, and precision irrigation. Surface irrigation is less effective in water use efficiency, but it is still by far the most common irrigation method due to relatively cheap operational cost and its practicality (Batchelor and Schnetzer 2018). Deficit surface irrigation practice can also be another alternative, albeit it is not popular in Indonesia's sugarcane plantations. Deficit irrigation can be construed as applying irrigation water below full crop-water requirements or evapotranspiration (Fereres and Soriano 2007; Shukr et al. 2021). With this practice, crops are exposed to a certain degree of water stress during a particular period or throughout the growing season without compromising the yield (Chartzoulakis and Bertaki 2015). Previous studies have assessed the feasibility of deficit irrigation and indicated that significant savings in irrigation water are possible without sacrifice sugarcane yield (Santos et al. 2019; Dingre and Gorantiwar 2021). Dingre and Gorantiwar (2021) observed that a water deficit imposed in the maturity stage was only marginal affecting sugarcane yield.

In Indonesia, irrigation infrastructures such as dams, canals, reservoirs, etc., are built to irrigate national's strategic commodity, notably rice and sugarcane, although rice is the most prioritised crop to get irrigation (Alaerts 2020; Pasandaran 2010). Therefore, information on how irrigation is practiced in sugarcane fields is very limited, although some scholars tried to fill those information gaps. For example, a study in the Kediri district, East Java, by Fahriyah et al. (2018) showed that most sugarcane farmers are technically inefficient in terms of their farming inputs, including labour for performing irrigation. Achieving high efficient irrigation in terms of water supply and productivity will be like "mission impossible", unless one solution called volumetric water pricing is implemented comprehensively (Rodgers and Zaafrano 2002; Vos 2002). In common, irrigation in Indonesia sugarcane plantation has not managed professionally since the 1950s, after the Dutch left the country. The absence of rules and regulations on irrigation management and its field efficiency monitoring is the underlying reason why efficient irrigation is never met (Sari and Wegener 2015; Pasandaran 2010).

Improved drainage of sugarcane plantation

In reverse to the drought, some areas may experience excessive rainfall due to climate change. Climate change may lead to frequent, severe, and unpredictable waterlogging (IPCC 2014). Waterlogging is known to bring physical, chemical, electro-chemical, and biological changes to the soil. Waterlogging due to heavy rainfall can reduce crop growth due to low germination and emergence, soil erosion, and soil nutrient loss. These adverse effects may be more severe if it occurs over a predominantly clay area with a low infiltration rate. La Nina, which is a phenomenon of an increase of rainfall above average, has been known to affect sugarcane productivity in Ngawi district, East Java, Indonesia. When La Nina occurs in the generative phase of sugarcane growth, sugarcane will continue to grow, and the maturity phase is delayed so that the commercial cane sugar can be lower (Indarwati *et al.* 2018).

A good drainage system is indispensable to alleviate waterlogging in sugarcane plantations (Manik et al. 2019), particularly in plantations with predominantly clay soil. During sugarcane cultivation, a good drainage system is often just as critical as a sufficient water supply. Improving the drainage of sugarcane plantations will generally lead to a rise in sugarcane productivity (Holden and McGuire 2014). Drain channels should be built along the edge of the field plot, and it needs to be connected to a nearby lake, river, or other water bodies as a place for the final discharge. When there are no water bodies available, it can be considered to build the artificial one. The artificial lake or retention basin can also act as a water reservoir for irrigation during the dry season. It will be costly to build such an artificial water body, but it can be used as a long-term investment (Sanghera et al. 2019).

Selection and use of suitable cultivars

The development of sugarcane cultivars resistant to stress is a tactical strategy in climate change adaptation (Zhao and Li 2015). Climate change may result in inadequate rain for agriculture; thus, selecting or breeding drought-tolerant cultivars will become more and more critical (Santos *et al.* 2019). Different sugarcane cultivars show distinct response and adaptation to stress, such as drought (Queiroz et al. 2011; Jangpromma et al. 2012; Santoso et al. 2015; Devi et al. 2018; Khonghintaisong et al. 2018; Chapae et al. 2020), waterlogging (Avivi et al. 2018; Avivi et al. 2020), heat (Kohila and Gomathi 2018), and salinity (Saxena et al. 2010). Santos et al. (2019) found that different sugarcane cultivars respond differently under a deficit irrigation treatment, whereas a higher water use efficiency under the limited water conditions was found for specific cultivars. The different response of sugarcane cultivars to environmental conditions is commonly associated with their physiological differences (Cardozo and Sentelhas 2013). Several researchers suggested that it is essential to develop sugarcane cultivars resistant to heat, drought, waterlogging, salinity, pest, pathogens, and a shorter maturity period (Mhlanga-Ndlovu and Nhamo 2019; Pipitpukdee et al. 2020; Sonkar et al. 2020). In the forthcoming, genetically modified sugarcane cultivars with improved resistance to various biotic and abiotic stresses would serve more towards sugarcane crop improvement (Singh et al. 2019).

It is prominent for sugarcane growers to select suitable cultivars with high yield potential and well-fitted to agroclimatic conditions (Batchelor and Schnetzer 2018). Some socio-economic factors should also be taken into account in picking suitable sugarcane cultivars (Figure 2). By far, there are numerous choices on local sugarcane cultivars in Indonesia, which have different tolerance to various stressors. Some drought tolerant sugarcane cultivars, e.g., MLG 1308 (Abdurrakhman et al. 2018), NXI-1T (Nurmalasari and Murdiyatmo 2012), Kentung, and Bululawang (Santoso et al. 2015). Some examples of waterlogging tolerant cultivars are PS 881 (Avivi et al. 2018) and VMC 76-16 (Avivi et al. 2018; Avivi et al. 2020). Under saline soil conditions, an example of tolerant sugarcane cultivars is PS 862 (Arrosyid and Sugito 2018). Some examples of sugarcane cultivars resistant to pest borers are PSJT 941, PS 851, PS 891, PS 921, and PSBM 88-144 (Achadian et al. 2011).

In the process of releasing the appropriate sugarcane cultivars, if there is a new potential cultivar, a so-called "introduction test" needs to be performed. Indonesian Sugar Research Institute in Pasuruan, East Java, Indonesia, actively releases new sugarcane cultivars and performing the introduction test in multiple sugarcane estates across Indonesia. Nevertheless, most Indonesian sugarcane growers, especially smallholders, tend to choose high-tonnage cultivars instead of high-sucrose-content cultivars. For instance, growers in Java tend to keep planting their Bululawang cultivars because of their high-tonnage cultivar and relatively good productivity. In the long term, keeping the same cultivar can potentially increase the infestation of pathogens and pests. Therefore, a high commitment of all stakeholders to implement the sugarcane cultivar arrangement is required (Ardana et al. 2016).

Green cane harvesting-trash blanketing (GCTB)

Increasing soil organic carbon stocks is one of ample attempts to mitigate GHG emissions. Generally, sugarcane

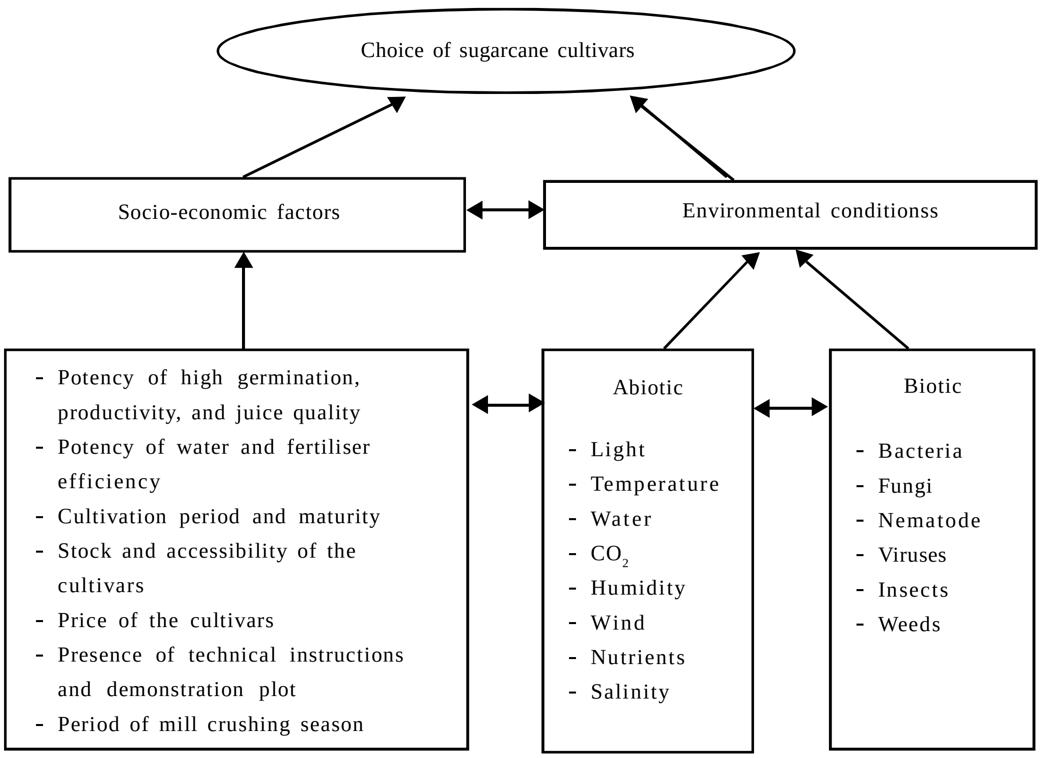

Figure 2. Factors to be considered in selecting suitable sugarcane cultivars within a given area (adapted from Zhao and Li 2015; Zainuddin and Wibowo 2019).

produces greater residues than other crops (Stirling et al. 2016). Freshly harvested sugarcane residues contain approximately 7-12 tonnes per hectares of organic matter and 3-5 tonnes per hectares of carbon (Robertson and Thorburn 2007). Retention of such residues in sugarcane plantations will affect soil carbon and nitrogen cycling, and hence GHG emissions. Sugarcane residues have traditionally been burned at harvest, but it is progressively being preserved on the soil surface as a 'trash blanket'.

Green cane harvesting-trash blanketing (GCTB) is an agronomic practice of returning sugarcane residues, i.e., dry leaves, left cane shoots, and the remaining sugarcane stalks back to the field after the harvesting process, as an in-situ organic matter (OM) source (Tórtora et al. 2013). The residues will be decomposed and being a source of organic matter (Putra et al. 2020). Carvalho et al. (2017) suggested that the positive impacts of implementing a trash blanket can be attained when at least seven tons per hectares of sugarcane residues are preserved on the soil surface.

GCTB has been considerably implemented and be a widespread practice in some sugarcane-producing countries such as Brazil (De Oliveira et al. 2015; Rasche and Diego 2020; Vianna et al. 2020), Colombia (James 2004), and Australia (Robertson and Thorburn 2007; Salter et al. 2010), as it is known to provide numerous benefits (Table 1). However, in other locations such as Indonesia, sugarcane growers tend to burn their sugarcane residues before harvesting rather than practising GCTB. Sugarcane harvesting by burning is indeed more practical, faster, and cheaper as it requires less labour, but it can potentially deplete soil organic matter, soil carbon, and nutrients from the decomposition process in a sugarcane field (Stirling et al. 2016) as well as causing air pollution.

The implementation of GCTB can be inaugurated by cutting sugarcane residues after harvesting with cutter tools, such as rotary mulcher or trash shredder. This residue-cutting step aims to accelerate the decomposition process, decrease pests and pathogens, and ensure ease of maintenance of subsequent sugarcane cultivation phase. Small pieces of residues are then be put on top of the line between sugarcane as inter-row. This step can be performed with a hay rake or wheel trash rake (Gunawan et al. 2017). After the cut sugarcane residues are put on the field, some types of activators can be applied to faster the decomposition process, such as urea, microorganism consortium, filter cake, etc. Wijayanti (2017) found that the addition of urea at four kilograms per hectare on the cut sugarcane residue lowered C:N ratio up to 10.9%, increased total soil nitrogen by 16%, and increased soil microbial population compared to the treatment without urea.

Not all inter-row should be filled with sugarcane residues. A 2-1-2 system can be used, whereas two inter-rows are kept empty, and one inter-row is filled with the residues. By such method, mechanical maintenance of sugarcane, comprising first and second fertilisation, first and second soil loose, and weeding of the subsequent sugarcane is still possible to be done on the empty inter-row. However, if fertilisation of the subsequent sugarcane will be performed through a fertiliser applicator (FA) equipped with a disc coulter, the 2-1-2 system can be ignored, or sugarcane residues can be spread evenly over the plantation (Gunawan et al. 2018).

Although GCTB offers numerous benefits, potential disadvantages should also be considered. From the perspective of sugarcane growers or sugar mills, the implementation of GCTB is not practical. Sugarcane growers may even need to invest some money to pay the labour or to purchase and operate tools to chop the sugarcane biomass.

Amendment of soil organic matter

The amendment of soil organic matter can positively impact the soil's physical, biological, and chemical

Table 1. Reported benefits of green cane harvesting-trash blanketing on soil and sugarcane growth by some foregoing studies in several locations worldwide.

Benefit(s)	References and locations of study
Improving soil organic matter	- Singh et al. (2012) in Muzaffarnagar, India - Liao et al. (2014) in Guangxi, China - Gunawan et al. (2017) in Jengkol, Kediri, Indonesia - Luca et al. (2018) in *São Paulo, Brazil*
Increasing abundance of soil micro and macrobiota	- *Tórtora et al. (2013)* in *Tucumán, Argentina* - Liao et al. (2014) in Guangxi, China - Sujak et al. (2018) in Asembagus, Situbondo, Indonesia
Suppressing weed growth	- Singh et al. (2012) in Muzaffarnagar, India - Concenço et al. (2016) in São Fernando Usine, Brazil
Reducing evapotranspiration/ conserving soil moisture at sugarcane field	- Olivier and Singels (2012) in Pongola, South Africa - Ng. Cheong and Teeluck (2015) in Savannah, *Médine and Saint Antoine, Mauritius* - Dhanapal et al. (2018) in Coimbatore, India

characteristics. Soil capacity to store water depends supremely on soil texture and structure. Although the texture is fixed, the structure can be improved by increasing soil organic matter (Batchelor and Schnetzer 2018). Several studies reported an increase in the abundance of soil organisms, including soil microbes, due to OM amendments (Balota and Auler 2011; Nair and Ngouajio 2012; Neher et al. 2013; van Horn et al. 2013; Zaccardelli et al. 2013; El-Sharouny 2014; Zhen et al. 2014; Sun et al. 2015; Francioli et al. 2016; Spiegel et al. 2018; Zhu et al. 2020) and fungi (Miura *et al.* 2013; Yang *et al.* 2018). The presence of these microbes contributes to nutrient cycling processes and aggregate formation (Rashid *et al.* 2016). Some of the beneficial microbes are called plant-growth-promoting microbes (PGPM), which can enhance plant growth and development by regulating plant hormones, producing siderophore, improving the antioxidant system, and rising nutrient acquisition in plants (Kumar and Verma 2018). PGPM can also help induce resistance of sugarcane against pests and pathogens and several abiotic stresses, such as drought and soil salinity (Naik *et al.* 2019).

Sundry types of OM can be used to amend sugarcane plantations, such as green composts from sugarcane residues or the other crops, manure, biofertilisers, or a combination of them (Djajadi 2015). Various by-products produced from sugar mills and sugarcane-based bioethanol distilleries such as filter cake or press mud, bagasse, and vinasse can also be used as OM (Dotaniya et al. 2016) (Figure 3). Utilising such by-products can even make sugarcane cultivation becomes more sustainable. However, such by-products cannot be instantly used as fertiliser. They should be first treated or composted before application; otherwise, they will cause environmental pollution. Raw filter cake or vinasse usually has a low pH, high biological oxygen demand (BOD), and high chemical oxygen demand (COD) (Prado et al. 2013).

As a C4 plant, sugarcane is able to produce a large quantity of biomass (Hoang *et al.* 2015). Some parts of sugarcane, such as young leaves and top leaves and sugar mill wastes, can be used as livestock feed. Therefore, it is possible to integrate sugarcane production with livestock production. Such integration provides a mutual advantage, as the livestock waste in the form of manure can be used as fertiliser for sugarcane. Through this concept, the cost for livestock food can be minimised as sugarcane biomass is cheap and easy to obtain, while the cost of organic fertiliser for sugarcane can be cut as the manure from the livestock can be used. Nevertheless, it should be noted that livestock waste will releases methane (CH_4) gas, which is one of the primary greenhouse gasses contributing to climate change. Methane is released from enteric fermentation, which is a digestive process occurring in ruminant livestock. Besides, methane is also emitted from the decomposition of livestock waste under anaerobic conditions (Berry *et al.* 2018). Various strategies can be performed and developed to reduce methane emissions, such as mitigation through biotechnologies (immunisation and biological control, the use of probiotics, and elimination of protozoa), mitigation through additives (addition of ionophore antibiotics and organic acids, and plant extracts such as condensed tannins, saponins, and essential oil), mitigation through feeding (choosing

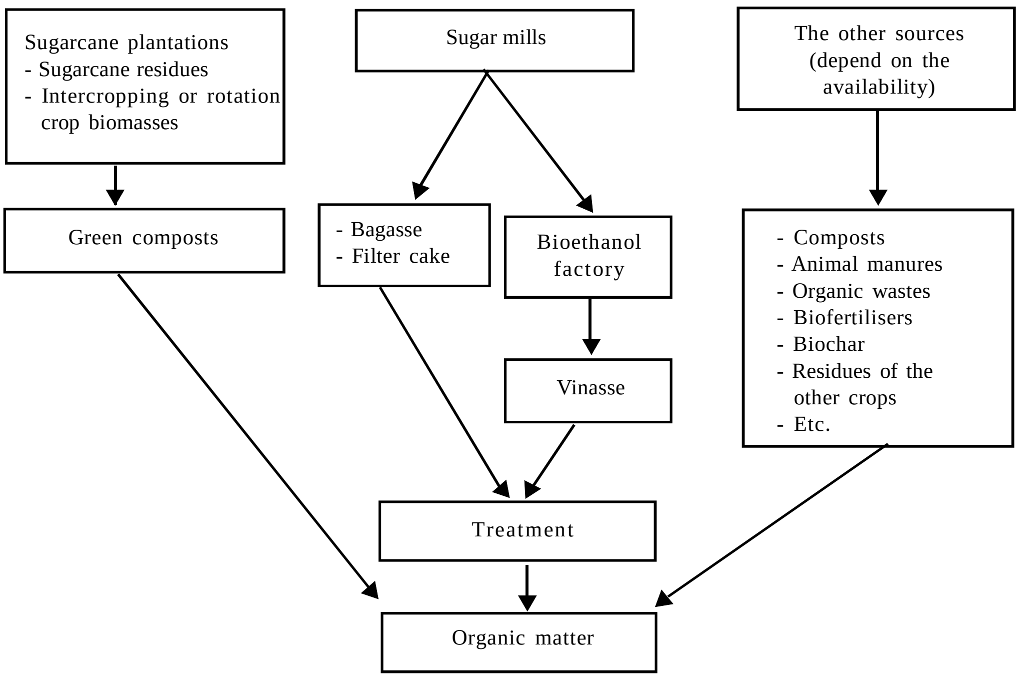

Figure 3. Several options of organic matter types to amend sugarcane plantation (adapted from Djajadi 2015; Dotaniya et al. 2016).

certain forages species and maturity, the use of concentrates in a certain level and nature, and the use of lipids in a particular level, nature, and presentation), etc. (Martin *et al.* 2010). Besides, livestock waste also needs to be managed to reduce methane emissions. For instance, the waste is being fermented using an anaerobic digester (Soelaeman and Maswar 2014) before being used as fertiliser.

Crop diversification

Enhancing the diversity of production at the farm and landscape level is a critical way to improve the resilience of agricultural systems (FAO 2013). In the sugarcane cultivation system, crop diversification can be raised through both intercropping and crop rotations. It has been shown to bring numerous benefits to both sugarcane and the environment. Biomass from the other crop can be incorporated into the soil; thus, it can increase soil fertility and maintain soil moisture (Batchelor and Schnetzer 2018). This benefit can be more significant if legume is used (Park *et al.* 2010; Stirling *et al.* 2010) as it can fix nitrogen from the atmosphere. This practice can also help break pests and pathogens cycle (Stirling *et al.* 2010), such as root pathogens, which often increase 11-30% of sugarcane yield (Ambrosano *et al.* 2013).

Intercropping can be performed by planting legumes or the other types of plants in the neighboring strip of sugarcane row at the time of sugarcane planting. Ideally, the crop type for intercropping in sugarcane cultivation is a short-lived crop. Thus, it can be harvested after three months, and the biomass can be incorporated into the soil. After three months, the sugarcane canopy will start to close, and the intercropping crop(s) cannot grow optimally due to the lack of sunlight. Meanwhile, crop rotation can be done by growing different crops in the same area across a sequence of growing seasons.

Crop diversification offers several benefits, but this practice is not yet popular and being implemented by Indonesian sugarcane growers (Putra *et al.* 2020). They may be indolent in applying intercropping since the positive impacts cannot be seen immediately after its implementation. It will take some time for nitrogen from legumes to be mineralised and available for sugarcane in a legume-sugarcane rotation system (Park *et al.* 2010). In the crop rotation system, sugarcane growers even need to spend money on removing sugarcane stumps, soil tillage, and planting (Srivastava and Rai 2012; Ambrosano *et al.* 2013). In Indonesia, sugarcane growers even do ratoon for more than the maximum recommended time for ratooning, i.e., three times (Pawirosemadi 2011), as it can reduce cultivation cost by 25-30% (Singh *et al.* 2012).

Precision agriculture

Climate change leads to unpredictable weather and its unbalanced distribution. This condition will undoubtedly increase the risk to sugarcane growers. Therefore, there is a need to change over conventional farming into a new approach which can adjust the dynamic change of weather condition (Nugroho *et al.* 2019). Precision agriculture (PA) is a method that comprises a set of technologies integrating information systems, sensors, enhanced machinery, and informed management to optimise crop production by measuring for variability and uncertainties within the agricultural systems (Gebbers and Adamchuk 2010).

PA allows sugarcane growers to irrigate and fertilise their crops using a precise amount of water and fertilisers at the right time, in accordance with the actual field condition (Shafi *et al.* 2019). Optimal quantities of fertilisers and pesticides in PA can lower the environmental impacts and reduce production costs without compromising the sugarcane yields (Silva *et al.* 2011; Prasara and Gheewala 2016). PA can also minimise eutrophication effects on water bodies near sugarcane plantations. Furthermore, PA can contribute to (1) optimisation of production efficiencies, such as agricultural water use efficiency to maintain the hydrological functions, (2) optimisation of crop quality, and (3) minimisation of risk to the growers (Bramley *et al.* 2015).

Among the examples of PA technologies applicable for sugarcane plantation are automatic planters or harvesters, satellite images, aerial photography, georeferenced soil sampling, satellite steering system, weed and disease sensors, as well as soil electrical conductivity sampling (Silva *et al.* 2011). Nevertheless, it should be noticed that PA is not merely the use of sophisticated technologies, although numerous new technologies can be concatenated as part of PA's management strategies. PA is more to a process that should be part of holistic farm management and action plan, with clear goals the grower wants to achieve (Bramley *et al.* 2015). Currently, the adoption of PA amongst Indonesian sugarcane growers is still low due to several reasons, such as relatively high investment in having PA's technologies and poor knowledge of sugarcane growers in operating these technologies (Putra *et al.* 2020).

Integrated pest management

Preceding studies indicated that climate change potentially generates a favorable environment for pest and pathogens infestations (Goebel and Nikpay 2017; Velásquez *et al.* 2018; Shrestha 2019), although climate change acts disparately on different pest or pathogens (Velásquez *et al.* 2018; Shrestha 2019). Climate change also causing plants to experience stress and attenuating their defensive system; thus, this condition will increase the susceptibility of the plants to pests and pathogens (Sharma 2016). Additionally, as a tropical and humid country, Indonesia is rich in biodiversity, including a wide range of pests (von Rintelen *et al.* 2017). There are more than a hundred types of sugarcane pests in Indonesia (Achadian *et al.* 2011). Indonesia also has an abundant number of pathogens, and some of the most baneful diseases for sugarcane with the highest production area are ratoon stunting by *Leifsonia xyli* and red rot by *Colletotrichum falcatum* (Velásquez *et al.* 2018).

Indonesian sugarcane growers, especially smallholders, often rely only on chemicals, i.e., synthetic pesticides and insecticides, to manage pests and pathogens. Climate change may affect the efficacy of these chemicals. Natural products such as biopesticides and entomopathogenic viruses, fungi, bacteria, and nematodes are also highly sensitive to environmental changes. A rise in temperatures and ultraviolet radiation, as well as a decrease in relative air humidity, may render those control tactics to be less effective (Sharma 2016). This condition has put forward new challenges for sugarcane production in Indonesia. Therefore, there is a need to develop appropriate pest and pathogen management strategies that will be effective under climate change. Proper pest and pathogen management are required in sugarcane cultivation to avoid economic loss. The integrated pest management (IPM) method, which combines some pest control tactics, can be considered rather than reckoning only one pest and pathogen control method.

The core principle of IPM is to lower pest populations by combining some pest and pathogen control methods other than chemicals, such as parasites, predators, pest pathogens, and biological pesticides so that it can minimise risk to people and the environment as well as the resistance of pest or disease to chemicals. Chemicals can be used only if the aforementioned "environmentally-friendly" methods cannot reduce pest populations (Diratmaja and Zakiah 2015). IPM also focuses on prevention rather than extermination. IPM should be ecology-based, whereas pest and pathogen control has to be adjusted with specific conditions and problems in a given area. Subiyakto (2016) proposed seven IPM tactics for sugarcane that can be practiced in a field scale, i.e. (1) land management, including trash blanketing and the use of strip crops as a green fertiliser, (2) the use of sugarcane seeds that are free from pest and pathogen and tolerant cultivars, (3) monitoring of pest and pathogen, (4) biological control, for example by using bio-agents and/or bio-pesticides, (5) mechanical control, such as cutting infected area of sugarcane and/or destroying pest's eggs and larvae found in sugarcane, (6) chemical control which is performed if the other pest and pathogen control methods gave no results, and (7) control based on government regulations or laws, for instance, quarantine to avoid the spread of pest or pathogens from an area to the other area.

The IPM has been promoted in Indonesia and regulated through Indonesian Government Regulation No. 6/1995 concerning Plant Protection. Unfortunately, IPM application in Indonesia is still uncommon. The chemical method is more preferred by sugarcane growers due to its practicality and lower cost. The implementation of IPM by Indonesian sugarcane growers is running slowly (Subiyakto 2016).

POSSIBLE DRAWBACKS OF CLIMATE SMART AGRICULTURE IMPLEMENTATION IN SUGARCANE FARMING

Although CSA offers numerous benefits in building the resilience of sugarcane cultivation under climate change, there are also some potential drawbacks of its implementation at the field level. CSA is bridging several disciplines together so that it can be challenging (Torquebiau *et al.* 2018). One primary drawback is a low level of awareness of sugarcane growers regarding climate change. Sugarcane cultivation needs high labour, and the human asset is essential. Not all growers have a good understanding of climate change or experiencing the direct decline of sugarcane production due to climate change.

Sugarcane growers cannot simply alter their 'business-as-usual' cultivation practice, such as changing their conventional irrigation method into deficit irrigation practice. Also, it may be challenging to select the suitable sugarcane cultivar within a given area since a cultivar is more suited to one area only rather than on all areas. When the government or researchers recommend a suitable cultivar, it may be challenging to convince the growers through the dissemination process of new sugarcane cultivars to change their present sugarcane cultivar into the new one. Indonesian sugarcane growers tend to choose cultivars that are popular and well known to bring a higher production, although it is an old cultivar. To deal with such challenges, we argue that empowering sugarcane growers is one of the decisive factors in the success of CSA implementation.

Another possible limitation to implement CSA is sugar mill policies. For instance, some sugar mills in Indonesia often request sugarcane growers to plant a specific sugarcane cultivar, although the recommended cultivars may not be suitable for a particular area. High investment may also be a restriction for smallholder sugarcane growers, such as GCTB application, which needs high labour or precision agriculture, requiring both high investment and knowledge for the operations.

IMPLEMENTATION AND POLICY IMPLICATIONS OF CLIMATE SMART AGRICULTURE

To ensure a successful implementation of CSA in the agricultural sector, including the Indonesian sugarcane industry, multiple stakeholders of the various layer should be involved, such as sugarcane growers, researchers, civil society, and policymakers (FAO 2013). To make a significant impact on CSA, investment and coordination are required, and its principles should be implemented across all sectors (De Pinto et al. 2020). They need to work closely to mitigate the potential adverse effects of climate change and increase sugarcane yields by a multidisciplinary approach (Zhao and Li 2015). Although the literature on CSA application on sugarcane in Indonesia is very limited, a study from Ariani et al. (2018) showed that the CSA has the potential to benefit the (rice) farmers and the environment at certain aspects, such as reducing greenhouse gas (GHG) emissions by 7-23%, and increasing economic return from the farming system by 42%. In addition, Simarmata et al. (2020) emphasised that to familiarise CSA implementation into a larger scale, there are several challenges to be faced, e.g., to meet the resilient farming system to climate change and sustainable production and income for farmers.

Stakeholder analysis has been performed, and stakeholders are pigeonholed based on their level of interest and power. Government, sugarcane growers, and sugar mills are categorised as having high power and interest, and they may have the largest impact on the success of the CSA implementation. Media and agricultural extension agents, as important dissemination agents of the CSA, are categorised as having high power but low interest. They need to be kept satisfied, although they may not be interested due to the high power to influence the growers. Research and development institute is categorised as having low power but high interest in the topic of CSA. Civil society is considered as a stakeholder who has low power and low interest (Figure 4).

Sugarcane-related policies, regulations, and programs regarding the CSA approach should be promoted or supported by the government at the provincial and municipal levels to sugarcane growers and sugar mills (Perdinan *et al.* 2018). Some types of information related to the CSA to be promoted to sugarcane growers or sugar mills are climate impacts on agriculture and the benefits of practising agronomic practices based on the CSA approaches (Surmaini and Agus 2020). This information can be disseminated through mass media or agricultural extension agents (Abegunde *et al.* 2020). Therefore, it is essential to improve the knowledge capacity of extension workers regarding CSA (Perdinan *et al.* 2018). Besides dissemination, the farmer field school model can be performed to make sugarcane growers informed regarding crop management decisions based on CSA approaches (Thorburn 2015).

Dissemination of CSA approaches through mass media and agricultural extension agents and a farmer field school can help growers and sugar mills manage climate risks and support CSA implementation. However, the level of success ultimately will depend on how well the communication with growers, whether the means of implementation is available at the local level, and whether the implementation can improve grower's short and long-term livelihood (Surmaini and Agus 2020). This attempt to raise awareness amongst smallholder sugarcane growers or sugar mills of the severe impacts of climate change on sugarcane production should be improved, particularly in

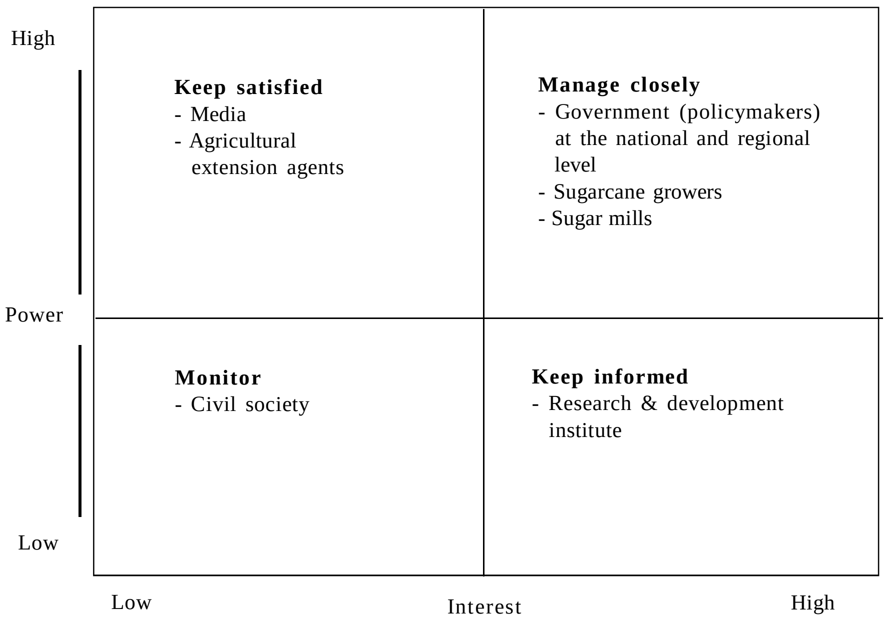

Figure 4. Stakeholder analysis matrix of climate-smart implementation in the Indonesian sugar industry (adapted from FAO 2013).

portended vulnerable areas in Indonesia. Sugarcane grower associations or groups, called “Gabungan Kelompok Tani” (GAPOKTAN), should also be strengthened as a network to improve farmers’ confidence in adopting CSA (Perdinan et al. 2018).

Besides raising awareness of growers and sugar mills, some budgets should be allocated for research. The government should support relevant researchers to study the impacts of climate change on sugarcane production at various locations in Indonesia and mapping vulnerable areas. Crop simulation models using multiple tools needs to be examined based on the agroclimatic zonation (Perdinan et al. 2018). Specific questions about the effectiveness of each aforementioned agronomic intervention to alleviating the adverse effect of climate change and to improving sugarcane growth in Indonesia should be answered by adequate field trials. Besides, researchers should also be encouraged to design tolerant cultivars using modern breeding and molecular biology and suggest agronomic practices which are feasible to be performed by smallholder and sugar mills. The government also needs to make a clear and specific guideline regarding CSA as a recommendation to sugarcane growers. Finally, one of the important notes to sugarcane plantation managers is that the complex interaction between CSA’s components must be contextualised into a long-term implementation plan, for instance, the irrigation and drainage system design, planting season according to climate forecast, and all relevant support system for cane production. The plan must comply with the readiness and preparedness degree of each plantation and their budget for CSA application.

CONCLUSIONS

Implementation of climate-smart agriculture in the Indonesian sugarcane plantations is imperative as sugarcane is a sensitive climatic crop, which can be prone to climate change and thus unfavorably impact its productivity. Although the concept is basically genuine in Indonesia, especially for sugarcane plantations, it offers an excellent opportunity to boost and sustain sugarcane production under the changing climate condition. This paper argues some agronomic interventions as strategic approaches of climate-smart agriculture in tackling the adverse effect of the changing climate, i.e., efficient irrigation, improved drainage of sugarcane plantation, selection and use of suitable sugarcane cultivars, green cane harvesting-trash blanketing (GCTB), the amendment of soil organic matter, crop diversification, precision agriculture, and integrated pest management. All the agronomical practices are equally important and contribute to increased sugarcane production. However, specific questions about the effectiveness of each mentioned agronomic intervention to alleviating the adverse effect of climate change and to boosting sugarcane growth in Indonesia should be answered by adequate field trials. Last but not least, to ascertain the success of climate-smart agriculture implementation, multi-stakeholders, i.e., sugarcane growers, researchers, civil society, and policymakers, need to be involved.

CONTRIBUTION STATEMENT

In this article, Rivandi Pranandita Putra acts as the main contributor, Nindya Arini, and Muhammad Rasyid Ridla Ranomahera as member contributors.

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