Climate Resilient Sustainable Agriculture for Restoring the Soil Health and Increasing Rice Productivity as Adaptation Strategy to Climate Change in Indonesia

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Abstract. Climate change (CC) is real and threatens the livelihood of most smallholder farmers who reside along the coastal area. The CC causes the rise of temperature (0.2-0.3°C/decade) and sea level (SRL = 5 mm/year), drought and floods to occur more frequently, the change of rainfall intensity and pattern and shifting of planting season and leads to the decreasing of crop yield or yield loss. Most of the paddy soil has been exhausted and degraded. About 50% of the rice field along the coastline is affected by high salinity and causes significant yield losses. The research was aimed to summarize the results of the system of organic based aerobic rice intensification (known as IPATBO) and of two climate filed school (CFS) in Cinganjeng and Rawapu that situated along the coastline of Pangandaran and Cilacap. Both IPATBO and CFS have adopted the strategy of climate-resilient sustainable agriculture (CRSA) for restoring the soil health and increasing rice productivity, and as well as to empower the farmer community. The implementation of IPATBO (2010-2020) in the different areas has increased the soil health, fertilizers, and water efficiency (reduce inorganic by 25-50%, and water by 30-40%) and increased rice productivity by at least 25-50%. Both CFS in Ciganjeng and Rawaapu were able to improve soil fertility, increase rice productivity, and farmer capacity. This result concludes the agro-ecological based CRSA and CFS can be adopted for the increasing the resilient of agricultural practices and farmers in adapting to climate change

Keywords: Climate change, resilience, soil health, adaptation, rice

Introduction

Indonesia as an agrarian country consisting of 17,480 islands with 91,000 km of coastline forces to increase the food production through agricultural intensification and extensification program. The intensive agricultural practices are adopted to produce enough food and other agricultural product for a rapidly growing population. The population growth is about 1.5 % (4-5 million per year) and is expected to be increased from 273 million in the year 2020 to 480 million by 2050 [1-2]. Consequently, agriculture practices are a force to become more intensive to boost food production and productivity for enhancing food security [3].
Most of the farmers are smallholders, of which 50-60% reside along the coastal areas, which are seriously affected by climate change. The agricultural practices and the farmers’ livelihoods in coastal areas are vulnerable to sea-level rise (SLR) that increases about 0.25 – 0.8 cm per year [4-7]. SLR causes the loss of arable land through inundation and increased soil salinity, affecting crop growth and yield. In fact, salinity stress is a common feature, as most lowland rice in Indonesia is located in coastal zones [3]. The inundation of some coastal districts of Java is expected to reduce rice production by 95% [8]. Furthermore, SLR increases the salinization of rice fields and causes significant yield loss or harvest failure, particularly in the dry season. Currently, it is estimated that about 50% of irrigated rice fields (at least 2.5 million ha) in the northern coastal regions of Java are becoming saline due to the SLR [3; 9-10].

The green revolution and intensive use of chemical fertilizers not only increases the productivity of agricultural crops but also accelerates the decomposition of soil matter. As consequence, most of the agricultural soils have been degraded and exhausted due to the over mining of essential nutrients. About 70% of paddy soils have a low organic carbon (less than 1.5%) and about 90% of dry land has been categorized as sick soil (low organic carbon and high acidity) [11-12].

Restoring the soil health of degraded agricultural soils plays an important role in adapting to the changing climate. Briefly, the management of soil organic matter (SOM) is a key success to improve and maintain the sustainability of soil health and crop productivity. Organic matter plays a significant role in improving the soil structure, moisture-holding capacity, diversity, and activity of soil organisms [13-15]. Moreover, organic matter acts as the pool for the energy and entry point of energy into the food web of the soil ecosystem [12; 16-17]. The latest studied reveal that application of 10-15 ton ha\(^{-1}\) organic manure (straw compost, compost, cow dung, green manure) combined biofertilizers with suitable water management and rice variety or adapted rice variety (flooding tolerant, saline tolerant and other traits) increased the resilient of soil health and rice productivity in coastline [1; 16-19]. The strategy climate-resilient sustainable agriculture (CRSA) includes: (1) integrated organic-based fertilizers management, (2) cropping system based on selected and adapted variety to the local ecosystem, (3) water-saving management, (4) farmers capacity building, and (5) promoting the entrepreneurship or community’s agribusiness [20-21].

Sustainable agriculture is all agricultural production systems and practices which are economically viable, environmentally sound, and socially acceptable and which contribute to a better quality of life for agricultural producers and their families and the general public [22-23]. In addition, the climate-resilient sustainable agriculture is defined as the science and practices of agroecology, and it contributes to both climate change mitigation (capture the carbon into SOM and ground biomass, and avoiding the emission of \(\text{CO}_2\) and other GHGs by reducing direct and indirect energy use) and adaptation [20; 24]. Moreover, ActionAid believed that agroecology-based Climate Resilient Sustainable Agriculture (CSRA) is an effective way to respond to both the climate and food crisis by overcoming the gaps of contemporary mitigation and adaptation programs. CRSA prioritizes the right to food, environmental conservation, and long-term community resilience in order to reduce food insecurity at the local level, and contribute to effective national and international climate change policies that support self-sufficiency. Simply, CRSA is based on the science and practices of agroecology, and it contributes to both climate change mitigation and adaptation. Furthermore, ActionAid promotes a three-prong approach of CRSA: (a) Conducting participatory appraisals to identify local conditions, potentials, and challenges, (b) Identifying, documenting, testing, and disseminating local knowledge and alternative agroecological practices and encouraging local innovation (c) Promoting long-term sustainability through appropriate agricultural research and extension services based on technologies that reduce the dependence on external inputs and agro-chemicals, help farmers adapt to climate change, and build on and reinforce local knowledge [20-21].
The key success of CRSA as an agroecological based agricultural practice highly depends on (1) integrated fertilizers organic-based and soil health management, (2) integrated crop and pest management, (3) capacity building and social engineering, and (4) communities entrepreneurship. This paper is focused with experiences on agroecological based agricultural practices: (1) promoting system of organic-based aerobic rice intensification (SOBARI), well known as IPATBO and categorized as water-saving technology in Indonesia [1] to restore the soil health and increase rice productivity, and (2) promoting the integrated the climate field school (CFS) as the main hub of exchange between academia, extension worker and farmers through a participatory and interdisciplinary research approach along the coastline of Pangandaran and Cilacap district of in Indonesia. Moreover, it is expected that this article could provide a clear and comprehensive and highlighting the results for promoting the CRSA.

Methods

This paper used the review method by summarizing the obtained secondary of the adoption IPATBO from 2010-2020 in Indonesia and summarized data of CFS from. Demo plots of IPATBO were mostly about one ha. The best practices that widely adopted are as follows; after land cultivation and preparation, the drainage canal (20 cm wide and 10 cm depth) were provided each 4 m distance within the plots to manage the water height or depth. Moreover, the drainage canals were also provided surrounding the plots to allow controlling the water excess [11]. Composted rice straw or fermented organic compost as bioameliorant was applied during land preparation. Young rice seedlings (12 – 15 days) of high yielding variety were planted with plant spacing about 30 x 30 cm or 30 x 35 cm. A single seedling is planted in twin methods (two single seedlings is planted in line about 5 cm distance from each other at the point of planting cross-section [1; 11]. The water-saving technology was adopted to allow rice roots growing properly and to stimulate the growth of soil organisms and as well as its biodiversity [25; 26]. Output oriented of integrated organic-based fertilizers management were adopted that consisted of (a) 2–3 ton ha⁻¹ straw compost, (b) 500 – 1000 kg of rice husk biochar, (c) 400-1000 g of biofertilizer as bioagent and combined with inorganic fertilizers (200 -250 of urea, 100 kg SP-36 and 50-100 kg of KCl), (d) organic liquid fertilizers were sprayed into the crop at 20, 30, 40, 50 and 60 [1; 11].

The experiments from 2017-2019 in two climate field school (CFS) in Ciganjeng and Rawaapu were established to (1) select the adapted rice variety to flooding and salinity, (2) investigate the effect of different organic fertilizers (cow dung, compost, green manure) on soil health and different productivity of rice variety [17; 27]. CFS of Ciganjeng villages situated at 7°34′44″S, 108°42′43″E, altitude: 12 m above sea level, has low soil fertility (0.82% org-C, 0.10% N), nonsaline and prone to flooding, while CFS of Rawaapu Village (7°37′59.0″S 108°45′51.5″E, Altitude: 4 m, saline due to tidal flooding, low soil fertility) [28]. A participatory and interdisciplinary research approach was adopted and involved 14 farmers (farmer researchers) in each village. The farmer researchers were directly involved in designing the research, the selection of organic fertilizers and rice varieties, and conducting the routine observations and measurement. The short training for the farmers was to measure plant growth and development, observe the climate parameters and soil fertility.

Summarized Results and Discussion

A. IPATBO

The adoption of IPATBO was able to increase the rice yield by 25–200% compared to traditionally flooded rice cultivation as shown in Table 1. Briefly, rice productivity was increased by at least 25% compared to the conventional methods as shown in Table [1]. In addition, the adoption of IPATBO has increased the soil health (CEC, and organic carbon, the biodiversity of beneficial microbes), reduced the inorganic fertilizers by at least 25%, and water irrigation by 30-40 % [1; 25; 29]. This result confirms that agroecological agricultural practices could improve soil health and rice productivity in sustainable ways [15].
The recycling of straw and rice husk to become composted straw and rice husk biochar could provide the organic fertilizers in a relatively high amount and reduce the inorganic fertilizers by at least 25%. Rice straw contains about 80% K, 40 N, and 30% of P of the taken up by rice accumulates in rice straw. Consequently, its incorporation can reduce the fertilizer requirement of the subsequent crop [29; 30]. The harvested rice straw contain about 0.5–0.8% N, 0.07–0.12% P2O5, 1.16–1.66% K2O, 0.05–0.1% S, and 4–7% Si [32].

Table 1. The summarized harvested rice yield of IPATBO in different locations in Indonesia

| Year     | Different Districts of Several Provinces | Grain Yield (ton ha\(^{-1}\)) | Increment compare to Conventional Methods |
|----------|----------------------------------------|-------------------------------|------------------------------------------|
| 2007-2015| West Java, East Java, Central Java, South Sulawesi, North Sulawesi, Nort Sumatera, Banten, Bali, NTT, etc. | 7.0-11.0 | 50-200 % |
|          | South Sulawesi (22 District), West Java( Cianjur, Ciamis, Karawang, Garut), Nort Sumatera (Samosir, Binjai, Deli Serdang), etc. | 6.0 -10.4 | 25-100 % |
| 2018     | Langkat, and Deli serdang, East Java (Jepara, Nganjuk), Bali ( Buleleng) | 6.5-9.6 | 25-50 % |
| 2019-2020*| Demoplot in SPLPP Ciparay Bandung | 7 – 7.5 | 25 % |

Source: [1; 11; 33]
Note: *Demo plot results in August 2020

B. Climate Field School

The soil fertility was improved significantly by the application of all organic manure compared to initial status (0.82% of org-C and 0.1% of N) in CFS of Ciganjeng. Briefly, the organic-C was increased by 11.83% to 56.38% and soils N by 23.08% to 64.29% (Table 2). This result confirms that the application of organic fertilizers improves soil fertility and soil health [12; 16]. Furthermore, Table 2 revealed that the application goat manure or goat manure combined with green manure (Azolla or Sesbania) resulted in the higher rice yield 5.62 – 6.22 ton ha\(^{-1}\) compared to the control (4.97 ton ha\(^{-1}\)). The yield increment was 13.0 – 25.2 %. In addition, the obtained rice yields have not differed significantly between organic fertilizers application. Based on the preferences of rice characteristics (taste and price), the variety of Ciherang and Mendawak were chosen by the farmers. The performance of different rice varieties was influenced significantly by sanity (Table 3). The Inpari 41 and Mendawak had resulted in the highest rice grain yield (4.28 and 4.32 ton ha\(^{-1}\)). Compared to the obtained yield by farmer surrounding the demo plot, these results were increased by about 80%. Additionally, the gaps between the potential yield of this rice variety (about 8 ton ha\(^{-1}\)) and the obtained yield are still high. Consequently, the opportunity to improve rice productivity by applying the organic ameliorant with the right dosage and composition is widely open [12]. Demo plot and training had contributed to the improvement of farmer capacity (Table 3). Briefly, the capacity of farmers increased from 44.25 to 67.8 in Ciganjeng and 48.86 to 69 in Rawaapu climate field school (CFS).
Table 2. Improvement of soil fertility and rice yield of different variety fertilized with organic fertilizers ($T_1 = 10$ tons of cattle composts; $T_2 = 10$ tons of cattle composts + $10$ tons of fresh green manure (*Azolla pinnata*) and $T_3 = 10$ tons of cattle composts + $2$ tons of fresh green manure (*Sesbania rostrata*) in CFS of Ciganjeng

| Observed Responds | Organic Fertilizers (ton ha$^{-1}$) |
|-------------------|-------------------------------------|
|                   | $T_1$  | $T_2$  | $T_3$  |
| Improvement of Soil Fertility |
| 1. Organic Carbon (%) | 1.82   | 1.82   | 1.52   |
|   • Initial carbon content (%) | 0.82   |        |        |
| 2. Nitrogen (%)       | 0.28   | 0.19   | 0.15   |
|   • Initial N content (%) | 0.10   |        |        |
| Rice yield of Different Variety (ton ha$^{-1}$) |
| Bangir              | 6.34   | 7.11   | 7.90   |
| Ciherang            | 6.67   | 7.37   | 6.84   |
| Inpari 34           | 6.51   | 6.80   | 6.78   |
| Mendawak            | 6.70   | 6.40   | 5.51   |
| Average rice yield (ton ha$^{-1}$) | 6.22   | 6.32   | 5.62   |
| Control: Farmers Yield (ton ha$^{-1}$) | 4.97   |  |  |

Source: [17]

Table 3. The demo plot results of different rice variety on the saline ecosystem in CFS of Rawaapu

| Variety     | Grain yield (ton ha$^{-1}$) | Increment (%) |
|-------------|----------------------------|---------------|
| Inpari 34   | 3.98$^a$                   | 67.9          |
| Inpari 41   | 4.28$^a$                   | 80.5          |
| Pelelawan   | 2.95$^c$                   | 24.4          |
| Inpara 02   | 3.08$^{bc}$                | 29.9          |
| Mendawak    | 4.32$^a$                   | 80.3          |
| Average     | 3.72                       | 57.0          |
| Average Farmers Yield | 2.37 | - |

Source: [27-28]

The increment were 52.74 and 41.23 %, respectively and belong to the category of the medium. This result confirms that the empowering of farmers through knowledge transfers were done effectively. Intensive interaction between the researchers and farmers are the key success to improve their experiences in developing the appropriate technology for adapting to climate change.

Table 4. The improvement of farmer researchers capacity of in CFS Ciganjeng and Rawaapu

| Location     | Average of | Factor g |
|--------------|------------|----------|
|              | Pretest    | Posttest | Increase (%) | Value | Criteria |
| Ciganjeng    | 44.29      | 67.64    | 52.74        | 0.42  | Medium   |
| Rawaapu      | 48.86      | 69.00    | 41.23        | 0.39  | Medium   |

Source: [34]
Conclusion and Closing Remark

Climate change (CC) is real and threatens the smallholder farmer who resides along the coastline of Indonesia. About 40% of Indonesia's population is highly vulnerable to the impacts of climate change. The CC causes more frequent droughts, heatwaves, floods, and other disasters. Additionally, CC effects the change of rainfall pattern, intensity, and shifting of cropping season and causes a significant loss of agricultural product and threatens food security. The rising of temperature about 0.2-0.3 per decade (estimated at 0.9-2.2°C by the 2060s and 1.1-3.2°C by 2100) and level see a rise (LSR) of about 5 mm per year are increasing the impact of CC, particularly for inhabitants on lowland areas along 91,000 m of coastline. In addition, most of the paddy soils have been exhausted and degraded (low organic matter, low pH, low nutrient availability) and high salinity along the coast. The agroecological-based climate-resilient sustainable agriculture (CRSA) strategy can be adopted for improving and maintaining the soil health, crop productivity, and increasing the resilience of the soil ecosystem and the farmers to adapt to climate change.

The adoption of IPATBO has increased the soil's health significantly and rice productivity by at least 25% in sustainable ways. Moreover, climate field school (CFS) was able to improve effectively soil fertility, rice productivity and to increase the capacity of smallholder farmers. The farmers in CFS of Ciherang and Mendawak variety combined with 10 ton ha$^{-1}$ of organic manure were chosen by the farmers in CFS of Ciganjeng, while the Mendawak and Inpari 41 were chosen by the farmers in CFS of Rawaaupu (strongly influenced by sea-level rise and salinity). The participatory action research approach and CFS are an important innovative strategy for increasing the resilient agricultural system and smallholder in dealing with a changing climate and need to promote globally.

Acknowledgements

We thanks to the support of the Academic Leadership Grant (ALG) program of Padjadjaran University and the Climate-resilient Investigation and Innovation Project (CRAIIP) funded by the German Non-Governmental Organization Bread for the World (first phase: 2017-2018).

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