CHILEAN JOURNAL of AGRICULTURAL RESEARCH

REVIEW

Indigenous technology of Banjarese-local rice cultivation system; a lesson learned for acid sulphate soils management

Arifin Fahmi[1*], Siti Nurzakiah[1], Izhar Khairullah[1], Aidi Noor[1], Nurmili Yuliani[1], Khairatun Napisah[1], and Rina Dirgahayu Ningsih[1]

[1]National Research and Innovation Agency, 16911 Cibinong, Bogor, Indonesia.
*Corresponding author (fahmi.nbl@gmail.com).
Received: 22 February 2024; Accepted: 31 March 2024, doi:10.4067/S0718-58392024000400562

ABSTRACT

Acid sulphate soils (ASS) can be classified as marginal soils due to their limited carrying capacity for rice (*Oryza sativa* L.) growth and production such as very low soil pH, high Fe content, and low soil nutrient content. A number of reclamation projects of ASS have not provided satisfactory outcomes due to a limited grasp of both the characteristics of the ASS and effective management methods. However, the precise cultivation system allows rice plants to grow well. The Banjarese-local rice cultivation system (BLRCS) is indigenous technology developed by Banjarese tribe in Kalimantan Island to enabling rice plant to grow and produce well in ASS. This review was addressed to provide scientifically describe and explain the chemical processes occurring in the soil under the BLRCS practice in ASS utilization for rice cultivation, consequently the utilization of ASS becomes more productive and environmentally friendly. The BLRCS is capable of enabling local rice plants to grow and produce well in ASS due to the improvement of ASS soil properties during growing season. Planting schedules were arranged based on the land hydrological conditions and use local rice varieties. The proper of land preparation and organic matter (OM) management in submerged condition during the growth and development stages of the rice plant lead Fe solubility becomes control, soil pH increase and nutrient in sufficient level for plant.

Key words: Acid sulphate soils, land preparation, organic matter management, *Oryza sativa*, rice cultivation, water management.

INTRODUCTION

The global extent of acid sulphate soils (ASS) is estimated 24 million hectares (Mha), they naturally exist along coastal plains and estuaries (Ritsema et al., 2000). In Southeast Asia, ASS is distributed along the coastal plains of Indonesia (Anda and Subardja, 2013), Malaysia (Shamshuddin et al., 2014), Thailand (Sukitprapanon et al., 2016), and Brunei (Grealish and Fitzpatrick, 2013). Drainage and reclamation of ASS may lead oxidation of pyrite and furthermore soil become severely acidic (Shamshuddin et al., 2014), hence only certain plants are able to growth and produce well. In tropical region, ASS are utilized for many plants commodity. However, since they are naturally situated in coastal plains and lowlands that frequently submerged accordingly ASS mainly utilized for rice (*Oryza sativa* L.) cultivation (Sulaiman et al., 2018).

Traditional management of wetland for rice cultivation have been carried out by farmers in several countries, such as the irrigated lowland culture system in the Philippines (Arnaoudov and Sibayan, 2015), wet-paddy cultivation system in Malaysia (Jackson, 1972), floating rice system and flood-recession dry-season rice system in Vietnam (Cramb, 2019), and Banjarese-local rice cultivation system (BLRCS) at Kalimantan Island, Indonesia (Khairullah and Saleh, 2020). Since hundreds of years ago, farmers from the Banjar tribe in Kalimantan Island have been cultivating local rice on tidal wetlands by transplanting and land preparation in several stages.

Currently, the rice cultivation method continues predominantly employed in areas with high levels of stress (marginal soils) or waterlogged soils due to poor drainage.

In Indonesia, tidal wetlands are distributed mainly in Kalimantan, Sumatra, Papua, Sulawesi and Java Island. In 1956, tidal wetlands reclamation projects were initiated such as Dredge, Drain, and Reclamation Program (Sari et al., 2023) and the reclamation of tidal rice fields (1969 to 1985) by Indonesian government (Noor et al., 2022) were conducted for wetland utilization for rice cultivation. Previously in 1936, tidal wetland in Kalimantan was reclaimed by Dutch Government through channel construction as long 25 km which connecting the Kapuas Murung River and the Barito River (Sulaiman et al., 2018). In recent decades, due to the increasing need for rice production and the decreasing availability of fertile lands on the Java Island, intensification of farming in ASS was conducted, namely by planting 2 to 3 times per year and using superior rice variety. Unfortunately, a number of these projects have not provided satisfactory outcomes due to a limited grasp of both the characteristics of the ASS and effective management methods. Since Inpara variety (superior variety) planted in ASS, average yield was only 1.99 t ha^{-1}, lower than its potential yield which reaches 5.0 to 7.0 t ha^{-1} (Koesrini et el., 2018). The severity of environmental pressure cannot be addressed with simple technology, the agricultural effort that can be perform involves adapting to natural conditions. Introducing the extensive and integrated technology with scientific based is required to utilize the soil to be more productive. Lack of knowledge and mismanagement contribute to damage and disruption of the tidal ecosystem.

Initially, most of agricultural land in tidal wetlands of Kalimantan is planted with local rice varieties, this condition is caused by the high preferences of the community regarding the ease of managing their crops and the high selling prices in the local market (Hastuti et al., 2019). The characterized local rice varieties have long duration (9-10 mo), are photoperiod sensitive, and relatively tolerant to Fe toxicity and soil acidity (Khairullah, 2020). Higher tolerance of local rice varieties to Fe(II) toxicity is thought to be caused by genetic factors that allow Fe(II) to enter the plant tissue. Generally, local rice varieties have low yield potential (1.5-2.53 t ha^{-1}) (Khairullah and Mawardi, 2022). More than 100 local rice varieties are cultivated in wetlands of Indonesia, and at least 40 local rice varieties are found in South Kalimantan. Local rice varieties are widely known in tidal wetlands of South Kalimantan such as Siam, Unus, Bayar, Pandak, and Adil clusters (Mursyidin et al., 2017), The use of superior varieties has not been able to replace the existence of local varieties, the technologies used have not been able to provide optimum results. The local rice cultivation in tidal wetlands by Banjarese farmers serve as a lesson learned in wisely managing ASS for rice cultivation, the indigenous technology has known to be environmentally friendly and has proven able to adapt on the extreme environmental conditions of the ASS. According to Hastuti et al. (2019) indigenous technology practices in tidal wetlands conserves the environment and realizes sustainable agriculture. This review was addressed to provide scientifical description and explain the chemical processes occurring in the soil under the BLRCS practice in ASS utilization for rice cultivation. Hence the utilization of ASS becomes more productive and environmentally friendly.

SOIL CHARACTERISTIC IN TIDAL WETLANDS

Tidal wetlands are the areas periodically flooded by seawater during high or spring tides or are affected by the cyclic changes in groundwater level (GWL) caused by the tidal cycle (New York State Department of Environmental Conservation, 2023). Nevertheless, the GWL or high standing water in tidal wetlands is also influenced by rain that falls directly on the land or upstream of the river (Fahmi et al., 2023). Indonesia has approximately 11.68 Mha of tidal wetlands, with 4.3 Mha classified as ASS (Noor et al., 2015).

According to the Soil Survey Staff (2014), ASS are classified into Entisol or Inceptisol orders (Table 1), the main difference between these two types of soils lies in the presence of the sulfuric horizon from the soil surface. The presence of the sulfuric horizon at a depth of < 50 cm leads soils from the Sulfaquepts great group to be more vulnerable to severe acidification, resulting it harder to utilize. Nevertheless, proper water management plays a key role in the success of agricultural cultivation in ASS soils (Shamshuddin et al., 2014).

Acid sulphate soils may be classified into marginal soil, their low productivity is related with one or more of the following unfavourable characteristics: Very low soil pH, high Al and Fe content, and low content of nutrients (Shamshuddin et al., 2014; Fahmi et al., 2023). Here are ASS soil characteristics that are often potential constraints of plant growth and development.

Table 1. Characteristics of two type of acid sulphate soils (ASS) in Kalimantan Island (Anda and Subardja, 2013).

Soil characteristics	Sulfic Endoaquepts	Typic Sulfaquents
pH H_2O	4.50	5.00
Electrical conductivity, dS m^{-1}	0.66	0.12
Organic-C, %	13.30	8.00
Total N, %	0.15	0.20
P_2O_5, mg 100 g^{-1}	62.00	59.00
K_2O, mg 100 g^{-1}	27.00	29.00
Exchangeable Ca, cmol kg^{-1}	5.50	8.00
Exchangeable Mg, cmol kg^{-1}	4.70	5.80
Exchangeable K, cmol kg^{-1}	0.20	0.10
Exchangeable Na, cmol kg^{-1}	0.20	0.78
Cation exchange capacity, cmol kg^{-1}	37.00	21.00
Al, cmol kg^{-1}	7.40	0.40

High soil acidity and high Fe content

In ASS, soil pH and redox potential (Eh) stated as master variables in biogeochemical cycling of elements and soil fertility (Sahrawat, 2015). Soil pH of ASS is classified as acidic to very acidic, ranging from 4.0 (Entisol order) to < 3.5 (Inceptisol order) (Soil Survey Staff, 2014); however, flooded ASS have higher soil pH (> 4.0) (Karimian et al., 2017). Pyrite is one of the main sources of ASS acidity (Jayalath et al., 2016). Several factors affect the magnitude of changes in soil acidity due to pyrite oxidation, i.e., oxygen and Fe(III) availability, decomposable OM, initial value of soil pH, base cation availability, pyrite content and land hydrological condition. However, soil moisture or land hydrological condition is the main factor that determine soil acidity of ASS (Karimian et al., 2017). Variations in GWL are a controlling factor of pH and Eh in ASS. Decreased GWL or soil moisture during dry season or due to land drainage leads oxidation of pyrite and other species of Fe(II). Conversely, flooded soil leads soil in reduced condition resulting soil pH increase (Karimian et al., 2017). In addition, flooded soil leads to Fe(II) concentration increase. The Fe(II) concentration in flooded ASS can reach 4700 mg kg^{-1} (Prade et al., 1986). The solubility of Fe in ASS highly depends on environmental conditions such as Eh, pH, OM, soil moisture, microorganisms, and the presence of anions (Karimian et al., 2018) and land management systems (Sukitprapanon et al., 2016).

Low nutrient content

Nitrogen content in ASS varies from low to very high (Anda and Subardja, 2013; Jayalath et al., 2016). Large stocks of N found in flooded ASS are associated with slow mineralization of the large OM content and OM management. Soil pH is an important factor which determines the availability and toxicity of nutrients in ASS, low soil pH causing Al and Fe solubility increase, they have large P fixing capacity (Zin et al., 2015). However, when ASS are flooded, the consequent lowering of the Eh then solubilise Fe-oxides thereby releasing bound P (Fahmi et al., 2023).

During the formation of ASS, the natural oxidation of sulphide-bearing minerals and sulfuric acid attack on clay minerals, result in the changes to the clay mineral structure. The sulfuric acid lowers pH which makes nutrients less available, low soil pH causing Al and Fe solubility increase, they displace K, Ca and Mg from exchange complex, so, exchange complex is occupied by Al and Fe. Therefore, ASS are likely to be deficient in Ca and K. Soil pH was positively and significantly correlated with exchangeable K, Ca and Mg content in soil (Dhanya and Gladis, 2017). However, flooded ASS increase availability of K, Ca and Mg due to increasing soil pH process and precipitation of Al and Fe (Sahrawat, 2015).

Nevertheless, ASS chemical properties are known very dynamic. According to Hanhart and Ni (1993) and Fahmi et al. (2023), the hydrological conditions of the land are the main factor determining the alteration of ASS chemical properties. The large impact of tidal fluctuations and rainfall on seasonal GWL causes the chemical properties of ASS forming a seasonal cycle (Figure 1). As stated by Karimian et al. (2018), the oscillations of Eh and pH in ASS are seasonal. Figure 1 shows the GWL beginning to rise in October when the rainfall starts (Figure 1), the highest peak of GWL occurs between December and February (peak of the wet season). Afterward, the GWL continues to decline, reaching the lowest point between August and September (peak of the dry season).

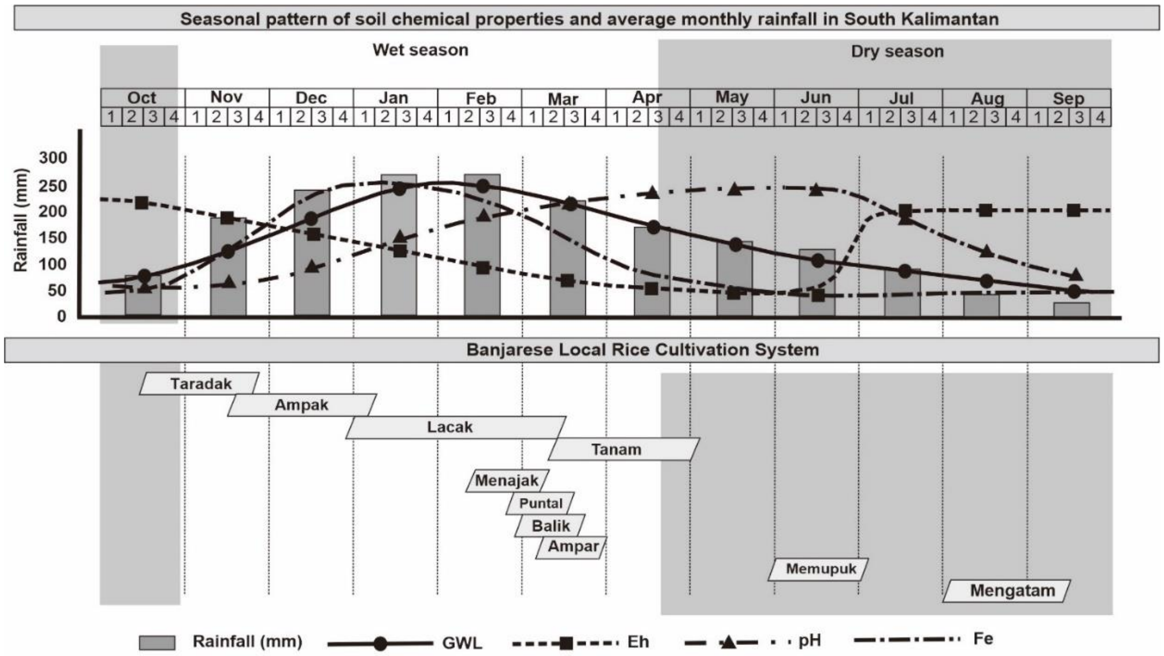

Figure 1. Seasonal pattern of soil pH, redox potential (Eh), Fe(II) and groundwater level (GWL) of acid sulphate soils (ASS) (modified from Hanhart and Ni, 1993) and average monthly rainfall in South Kalimantan (Sukmara et al., 2022) (top image) and planting schedules based on Banjarese-local rice cultivation system (BLRCS) (modified from Khairullah and Saleh, 2020) (bottom image). *Taradak*/*menaradak*: Seeding in the hole; *ampak*/*meampak*: transplanting seedlings which aged 30 to 40 d from *taradak* plot to the edges part of the rice fields (*ampak* plot); *lacak*/*melacak*: transplanting rice seedlings which aged 71 to 120 d from *ampak* plot to the apart of the rice fields (*lacakan* plot), usually located in the middle of a rice field; *tanam*/*menanam*: planting (final transplanting) rice seedlings which aged 126 to 140 d from *lacakan* plot to the rice field; *menajak*: doing the land clearing using *tajak* (cutting tool with long handle that is looks like a golf club); *puntal*/*memuntal*: piling up the cuts of weeds and bushes into ball-shaped lump; *balik*/*membalik*: reversing the lumps of cuts of weeds and bushes to accelerate decomposition processes; *ampar*/*meampar*: scattering the lumps of cuts of decomposed weeds and bushes throughout on the surface of the rice field; *Memupuk*: fertilization; *Mengatam*: harvest rice.

Soil acidity levels fluctuate throughout the year, with the lowest soil pH values occurring at the end of the dry season (August) until the beginning of the wet season (December) (Figure 1). This condition is related to intensive oxidation of ASS during dry season previously, followed by intensive flushing of soil acidity at the beginning of the wet season. After this period (March to June), the soil pH starts to elevate. The increased water volume during the wet season leads submerged soil for long time, increasing soil pH (Hanhart and Ni, 1993).

The dynamics of Fe(II) concentration in ASS throughout the year is closely related to GWL fluctuations (Figures 1), Fe(II) concentration starts to increase with the rising GWL, reaching the highest concentration shortly after the peak of GWL. Subsequently, Fe(II) concentration begins to decrease as the GWL declines. The decrease in Fe(II) concentration is caused by the oxidation process, which also leads a decrease in soil pH (Karimian et al., 2017). The concentration pattern of Fe(II) is influenced by various factors, including the slower rate of reduction reactions of Fe(III) compared to Fe(II) oxidation process, according to Reddy and DeLaune (2008) the reduction reactions of Fe(III) occur after the reduction of O_2, NO_3, and Mn(IV), after completely reduced under saturated conditions, Fe(II) tends to precipitate and adsorb on exchange complexes.

BANJARESE LOCAL RICE CULTIVATION SYSTEM

In general, Banjarese tribe applied BLRCS in all wetland types, from upstream area (freshwater swampland) until downstream area (brackish to coastal area). Banjarese farmers in freshwater swamp area apply BLRCS to avoid soil waterlogging on their rice fields during the reproduction and ripening stage of rice. The Banjarese farmers in ASS of tidal wetlands use BLRCS to avoid very high acidity and Fe(II) concentration during the early stages of rice growth, while the BLRCS in brackish to coastal areas is to prevent saltwater intrusion into their fields during the grain filling stage. This paper will focus on the practice of BLRCS as a strategy to avoid high acidity and Fe(II) concentration in ASS.

In tidal wetlands, most of rice fields are planted with very popular local rice varieties, especially in regions that frequently experience alternate drying-flooding, this practice is related with their excellent tolerance to severe environmental stress, such as high Fe concentration and very low of soil pH or saline water intrusion. However, Khairullah et al. (2005) showed that Fe(II) concentrations in ASS planted with local rice varieties were higher than critical limit of ferro (Fe(II)) concentrations, where 'Bayar Palas' (1.126 mg kg^{-1}) and 'Cisokan' (1.113 mg kg^{-1}), the local rice varieties characterized in the field visually did not show any Fe(II) toxicity symptoms. Audebert (2006) stated the critical concentration for the occurrence of Fe(II) toxicity for rice is > 500 mg kg^{-1} in the soil.

Proper water management is essential for successful and sustainable ASS reclamation. Dry-wet cycles will likely affect biogeochemical processes, water quality and quantity determine the direction of most biogeochemical reactions in wetlands (Stirling et al., 2020; Fahmi et al., 2023). The most important effect of soil flooding is reduced or ceased O_2 supply. As a result, soil in reduced condition then triggers a series of physical, chemical, and biological processes. Sahrawat (2015) stated that soil submerging is a powerful driver of changes in fertility and nutrient availability through two most important determinants of soil fertility namely pH and Eh. The fundamental role of pH in regulating the dynamics of major and micronutrients, toxins, and reduction products in soil solution. Redox potential and pH are drivers of soil-plant-microorganism interaction systems (Husson, 2013). This indicates that in natural circumstances, the fertility of ASS varies seasonally based on land hydrological conditions. Without high input technologies, cultivating rice in ASS can only be accomplished by adjusting on rice cultivation system. Farmers in Kalimantan deal with implementation of a traditional rice cultivation system that adapts to seasonally characteristics of ASS. They set planting schedules based on the prevailing land hydrological conditions and use rice varieties with robust adaptability to extreme ASS conditions or risk of saline water intrusion in coastal areas. They maintain GWL on rice field via irrigating, soil flooding and subsequently land draining in a simple water management system. Periodically, water alternately flooding-flushing out from the rice field following the tidal cycle. Meanwhile, to maintain the water level in the rice fields, farmers build water gate/*tabat* on the water channels around the rice fields (Hastuti et al., 2019). Previously, Sahrawat (2005) stated that traditional way of growing lowland rice involves land preparation by cultivation of the soil in flooded or wet state (puddling), followed by transplanting rice of seedlings and then growing rice in a flooded soil condition.

Most of ASS in tidal wetlands is planted with local varieties of rice. Meanwhile, in areas that have relatively light stress levels or areas where the hydrological system has been well managed, the traditional rice cultivation system has begun to be abandoned. Farmers in such areas have started using superior rice varieties and adopting mechanization technology. Nevertheless, the essence of this new cultivation system approach remains rooted in the traditional rice cultivation system. Typically, alterations in cultivation systems are made due to labour issues, land capability and the presence of government recommendations to enhance land productivity through utilization of superior varieties and mechanization. However, the alteration in rice cultivation systems is mainly due to improvements in rice field conditions. Changes in soil characteristics and improvements in land hydrology systems result in enhanced land quality, enabling the implementation of superior varieties and mechanization, application of soil ameliorants such as liming, organic and inorganic fertilizer. On the other hand, although unfavourable soil conditions have been tried to be improved previously, some farmers persist in applying the traditional rice cultivation system, as it allows for rice grow even in the low yields. For centuries, BLRCS has been recognized and remains employed in the cultivation of local rice, continuing its relevance until today, even in unfavourable soil condition. The lack of BLRCS is low grain yield production and requires an extended period.

The BLRCS in tidal wetlands areas covers several stages, including seedbed preparation, land preparation, transplanting, planting, fertilization, pest management, harvesting, and post-harvest processing (Khairullah and Saleh, 2020). This paper will focus specifically on seedbed preparation, transplanting and land preparation in the BLRCS based on soil chemical perspectives. The stages of local rice cultivation and the supposed soil chemical processes occurring within it are elaborated below.

RICE SEEDING AND TRANPLANTING

In lowland rice cultivation, two basic methods of sowing are transplanting and direct seeding. In BLRCS, transplanting is carried out into two stages (multiple transplanting system), seeding in the hole (*taradak*/*menaradak*) and transplanting of seedlings. Transplanting seedling is carried out in several stages (multiple transplanting), namely: Transplanting 1 (*ampak/meampak*), transplanting 2 (*lacak/melacak*) and planting (*tanam/menanam*). *Menaradak* typically begins in October to November (Figure 1), rice seedlings at this stage are called *taradakan* (Figure 2). Farmers usually apply wood ash or rice husk ash and occasionally small amount of lime on the seeding hole. This seeding activity is carried out at the end of the dry season or towards the beginning of the wet season. The *menaradak* is conducted on raised beds or slightly elevated plains to prevent the seeds from being submerged and to avoid soil properties in rice fields that are still unfavourable for rice plants, such as very low soil pH and high Fe(II) concentrations (Figure 1). According to Hanhart and Ni (1993) and Multazam et al. (2021), a significant amount of dissolved acid resulting from oxidation in the previous dry season is leached out at the start of the wet season. At those moments, ASS is in low fertility level, soil pH is around its lowest point (Janssen et al., 1992; Hanhart and Ni, 1993), and Fe(II) solubility starts to increase reaching the toxic levels (Hanhart and Ni, 1993). These acidic and toxic elements have potential to accumulate in rice fields.

Figure 2. Several stages of land preparation and transplanting of rice in Banjarese-local rice cultivation system. *Taradakan*: rice seedlings which 30 to 40 d old located on raised beds or slightly elevated plains; *ampakan*: rice seedlings which aged 31 to 81 d located on the edges part of the rice fields; *lacakan*: rice seedlings which aged 71 to 120 d located in the middle of a rice field; *tanam*/*menanam*: planting rice seedlings which aged 126 to 140 d from *lacakan* to the rice field; *menajak*: doing the land clearing using *tajak* (cutting tool with long handle that is looks like a golf club); *puntalan*: lump (ball-shaped) of cuts weeds and bushes.

After seedlings aged 30 to 40 d, seedlings are transplanted (*meampak*) to the edges part of the submerged rice fields, rice seedling at this stage are called *ampakan* (Figure 2). Each clump of rice is divided into 4 to 5 parts, each of which is planted in the *ampakan* plot. The *meampak* activity occurred simultaneously as the soil properties begin to improve, soil pH slowly starts to increase gradually and Fe(II) concentration slowly starts to decline gradually (Figure 1). This condition is related with leaching processes in soil due to increasingly heavy rainfall, marked by the rise in water standing volume (Figure 1). Furthermore, after 40 d, the *ampakan* are anew transplanted (*melacak*) to another part of the paddy field (*lacakan* plot), rice seedling at this stage is called *lacakan*. *Lacakan* plot is wider than *ampakan* plot (approximately 0.1 ha) (Figure 2). Similar to the *meampak*, each clump of rice is divided into 4 to 5 parts, each of them is planted in the *lacakan* plot. *Melacak* activity is carried out from the end of January (peak of the wet season) until the end of March (when rainfall starts to decrease, and the GWL had gradually recede) (Figure 1). At those time, the soil pH is sufficiently high and the solubility of Fe(II) is towards the lowest point (Figure 1). The seedlings remain in *lacakan* plot for about 55 to 60 d (depending on the GWL) before being transplanted (*tanam*) to the rice field (conducted from March to May). At those time, the soil pH is around its highest point and Fe(II) is around its lowest concentration (Figure 1). During this waiting period, farmers utilize the time to continue land preparation activities and manage OM. Transplanting local rice seedlings extends over 4 mo, revealing an inefficiency of time that could otherwise be harnessed for cultivating superior varieties within a single planting season. However, due to high standing water in the rice field, it is impossible to directly transplant seedlings (*taradakan*) from *taradakan* plot into the rice field. The multiple transplanting system in BLRCS indirectly aims to enlarge, strengthen, and multiply the tiller number. Atulba et al. (2015) found that the rhizosphere-oxidized area increased with the growth stage and root biomass of rice.

Land preparation

Land preparation in BLRCS consists of soil tillage and OM management, they are carried out simultaneously (Khairullah and Saleh, 2020). Land preparation begins in the second week of February, precisely after the *melacak* activity were completed (Figure 1). The land preparation system in BLRCS is known as *tapulikampar*, which is an abbreviation of *tajak-puntal-balik-ampar* (cutting-piling up-reversing-spreading). Land preparation begins with cutting weeds using a tool called *tajak*. *Tajak* is a cutting tool with long handle that is looks like a golf club. The use of a *tajak* is similar to motion of swinging a golf club (Figure 2). The land clearing from weeds with *tajak* is called *menajak*. The *tajak* cuts the weeds at the bottom of the rice stem (± 5 cm below the soil surface). Consequently, when cutting weeds with *tajak*, indirectly the soil is also cultivated to a depth of ± 5 cm (minimum tillage). *Menajak* is carried out under submerged soil conditions only. Land preparation technique (*menajak*) is addressed to avoid disturbance to the pyritic layer, prevent severe soil acidification due to pyrite oxidation. The cutting of weeds and bushes are allowed to remain in the field under submerged conditions. After 15 to 30 d, the cuts of weeds and bushes are piled up (*puntal*/*memuntal*) into ball-shaped lump (*puntalan*) (Figure 2). Approximately 7 to 10 d later, these lumps are reversed (*balik*/*dibalik*). Sometimes, new weeds may sprout from the lump, necessitating chopping to accelerate the decomposition process. As the GWL decreases due to the decreasing volume of rainfall (about 20 to 30 d after reversing the lumps), the lumps are distributed throughout on the surface of the rice field (*ampar*).

Practically, land preparation process in BLRCS can be viewed from two main aspects, namely OM management or composting crop residues method and soil flooding. The following will describe the soil chemistry processes that occur behind the land preparation method in the BLRCS.

Organic matter management

Tapulikampar is a Banjarese indigenous technology of OM management in tidal wetlands of Kalimantan. *Tapulikampar* is carried out in rice field under high waterlogging. In waterlogged condition, the cutting of weeds and bushes are allowed to decompose on rice field. The OM decomposition in submerged conditions is a prolonged process, Sahrawat (2015) stated that decomposition of OM in submerged soil is slower than in aerobic soils. In the submerged soils, OM decomposition is retarded because of lower C assimilation rates of anaerobic bacteria (Fageria et al., 2011). The OM management indirectly accelerates Fe(III) reduction which encourages an increase in soil pH and Fe(II) concentration (Bautista et al., 2023). This implies that soil flooding may have positive impacts, it also has the potential for adverse effects on rice plants. However, with proper land drainage system, the potential of Fe(II) toxicity can be avoided, Fe(II) is discharged concurrently with drainage water (Burton et al., 2006). In addition, along with the decomposition process, Fe(II) gradually undergoes fixation by high molecular weight organic acids produced by the advancing decomposition process.

The presence of OM in soil increases the mobility and solubility of Fe through reduction reaction (Fuss et al., 2011) and chelation (Karlsson and Persson, 2010).

Organic matter has an important role in the biogeochemical properties of wetland soils (Reddy and DeLaune, 2008). The application of OM to lowland rice culture is needed to maintain wetland soils fertility, this role is largely determined by the quality and quantity of OM, specific properties of ASS and the hydrological conditions of the land (Fahmi and Sarwani, 2013; Kölbl et al., 2018). *Tapulikampar* is a natural OM management system. Composted weed residues in the field can serve as a nutrient source. The utilization of composted weed residues in the rice field as a nutrient source is highlighted by the absence organic or inorganic fertilizers application in the BLRCS, as indicated by Purnomo et al. (2010). According to Noor et al. (2006), *Eleocharis dulcis*, as a dominant weed in ASS, contains 3.36% N, 0.43% P, 2.02% K, 0.26% Ca, 0.42% Mg, and 0.76% S. The application *E. dulcis* compost enhanced soil pH, Mg and Ca concentration, and cation exchange capacity (Hayati et al., 2020). Meanwhile, compost from a mixture of weeds such as *Eleocharis* sp., *Panicum repens*, *Rhynchospora* sp., showed 1.96 %N, 0.6% P, and 0.64% K (Alihamsyah et al., 2004). The returning 5 t ha^{-1} rice straw to the rice fields can provide a nutrient contribution of 15-26 kg N, 21 kg P, and 30 kg K (Fahmi et al., 2015).

Organic matter management under submerged conditions is ameliorative for soil fertility. Organic matter in ASS can act as electron donors during reduction processes of Fe(III) (Reddy and DeLaune, 2008). The presence of rice straw and easily decomposable weeds leads to a rise in soil pH through reduction processes (Fahmi and Sarwani, 2013) and the dissolution of base cations during decomposition processes (Reddy and DeLaune, 2008). As highlighted by Davranche et al. (2013), OM plays a key role in the solubility of Fe. The availability of easily decomposable OM can accelerate Fe(III) reduction, leading soil pH increase (Kölbl et al., 2018). Organic acid produced from OM decomposition triggers Fe(III) reduction. Glissmann and Conrad (2000) reported that acetic acid is the dominant organic acid produced in the early stage of decomposition processes. According to Kyuma (2004) oxidation of acetic acid is always simultaneously with reduction of Fe(III) to Fe(II). Over time, OM increasingly decompose, soil fertility enhancements not solely from the soil inundation process, but also attributed to the Fe chelation process, as documented by Fahmi and Sarwani (2013), which encourages an increase in P availability through suppressing P fixation by Fe (Sundman et al., 2016). At this time, rice plants have been planted on the rice field.

Soil flooding

During land preparation and transplanting process, the rice field remains consistently flooded, and the water freely flows in and out of the field in alignment with tidal fluctuations. Indirectly, this condition causes:

1. Increasing of soil pH. Soil inundation prevents the oxidation of pyrite, indeed decrease the pH of ASS. In addition, water management system accelerates and enlarges soil pH increase, and enhances availability of nutrients (Fahmi et al., 2023). According to Creeper et al. (2015), the flooding of ASS not only enhances soil water quality but also facilitates the leaching of soil acidity through tidal flushing.
2. Decreasing of Fe concentration in rice field. The applied water management system also works to flush dissolved Fe that accumulate in rice fields to the open water. During soil flooding, Fe(II) is released by the reductive dissolution of Fe-oxide minerals in soils (Sukitprapanon et al., 2016). Sylla (1994) suggests that excessive acid and soluble salts on the soil surface can be eliminated through tidal flushing. High-quality water proves highly effective in flushing Fe from soil solutions. Willett et al. (1993) documented the release of acids from areas surrounding oxidized ASS into open water.

RICE PLANTING

After undergoing the lengthy process of sowing and transplanting from *taradak* to *lacak* (transplanting 2), rice planting was finally carried out in March/April when the water levels gradually decline. Scientifically, currently the chemical properties of the ASS are in the best condition to support plant growth, characterized by the highest pH and lowest Fe solubility (Figure 1), thereby protecting the planted seedlings from Fe(II) toxicity. In addition, based on the stage of growth, rice seedlings are robust and sufficiently developed to withstand the extreme environmental conditions.

In the BLRCS, fertilization is not a common practice. Without fertilizer, the local rice yield range 1.5 to 2.5 t ha^{-1} (Khairullah and Mawardi, 2022), which have been considered quite satisfactory compared to rice production in ASS of Thailand (rice yield range 0.9 to 2.2 t ha^{-1}) (Attanandana and Vacharotayan, 1986). However, ASS are marginal soils, field observations prove that in the BLRCS, soil and water in the rice growing environment have been able to provide essential nutrients throughout the growth and development stages of the rice plants. According to Sahrawat (2015), wetland rice soils should be kept flooded for 4 wk prior to planting, as by following this practice most of the nutrients will be released in available form from soil for the rice seedling to utilize. Apart from the decomposition of OM, nutrient availability for plant growth is obtained through land management processes such as flooding (Fageria et al., 2011) and deposition from floods sediments (Venterink et al., 2006), as well as OM management (Fahmi and Sarwani, 2013). In addition, the nutrient sufficiency for rice is also derived from the presence of arbuscular mycorrhizal (AM) fungi around the rice plant roots through mutualistic symbiosis, as highlighted in studies by Purnomo et al. (2005).

After planting, during the entire growth period, rice crops are cultivated in flooded conditions, with GWL maintained at approximately 5 to 10 cm above the soil surface. Roughly 90 d later, rice field is drained to support the generative process (ripening stage). Finally, rice harvest carried out approximately 30 d later, when the rice grains exhibit a yellowish colour.

LESSONS LEARNED FOR FUTURE PERSPECTIVE

Acid sulphate soils with very low soil pH, high Al and Fe content, and low content of nutrients are dominant marginal soil in tidal wetlands. The BLRCS enhances the utilization value of ASS, an essential component within the BLRCS involves establishing the planting schedule, which is determined according to the land’s hydrological conditions. Soil pH and Eh are main determinants in soil fertility of ASS (Sahrawat, 2015), their dynamics are mainly influenced by the land’s hydrological conditions. Many ASS experts state that proper water management is essential key in the successful of agricultural cultivation on ASS (Bloomfield and Powlson, 1977; Shamshuddin et al., 2014). However, rice production in ASS may be enhanced more optimally, especially in areas with lighter environmental stress, such as ASS from Entisol. Due to their higher pH value, one or more of the BLRCS components can be modified or replaced, such as replacing local rice varieties with superior varieties. The application of BLRCS principles on non-native farms with other new technology in broader agricultural practices and management of ASS is absolutely required to increase rice production:

1. The BLRCS serves as a foundation for the innovation or formulation of novel technologies. Every component within BLRCS may inspire the creation of new, eco-friendly technologies that are both effective and sustainable. The use of *tajak* illustrates minimum soil tillage practices, which could lay the groundwork for the design and production of tractors specifically engineered to till the soil at shallow depths.
2. Modify with more modern technology, the use of agricultural machinery can significantly enhance efficiency across various aspects. However, selecting machinery that has the minimum effect on altering soil characteristics is essential.
3. Introduce modern technology. This effort is the most difficult option to undertake because replacing a technology component that possesses special characteristics requires a replacement that should ideally have the same or better characteristics without negative impact, such as replacing local rice varieties with superior varieties that have shorter lifespans and higher yields.

The BLRCS is an approach that can be carry out to minimize the negative impacts of ASS utilization for rice production. This implies that the utilization of ASS through BLRCS is crucial to prevent land degradation. Consequently, any attempt to modify one or more of the BLRCS components may alter chemical equilibrium in soil, which must be counterbalanced with new inputs and strengthening or modifying other components with environmental safety. Any attempt to replace BLRCS components must be based on the deep studies and research, hence each modification effort results agricultural businesses more profitable and have minimum negative impact on the environment. For instance, the replacement of local rice varieties with high yielding varieties, at least must be followed by subsequent steps, such as:

1. Applying mineral fertilizer, superior rice varieties typically have higher nutrient demands.
2. Soil liming due to some superior rice varieties are not tolerant to high soil acidity.

3. The use of short-duration rice varieties must be accompanied by a perfect land arrangement and water management system, as the annual dynamics of soil chemical properties need to be modified to support plant growth and production requirements. Modifying ASS properties most effectively is through managing the land's hydrological conditions as previously explained by Sahrawat (2015).

Table 2 shows the use of 'Inpara 1', 'Inpara 2' and 'IR64' (superior rice varieties) give different results in the treatment of several types and doses of ameliorants in ASS with a one-way flow water management system. Based on the ameliorant treatment, the highest yield was obtained from 'Inpara 1', while based on the rice variety, the highest yield was obtained in the ameliorant treatment 5.0 t ha^{-1} rice straw + 5.0 t ha^{-1}*E. dulcis*. These results indicate that any attempt to replace local varieties with superior varieties provide optimum results if followed by modification of other technology components.

Table 2. Effect of amelioration treatment on grain yield of three superior rice varieties in acid sulfate soil (ASS) (Khairullah, 2012).

	Ameliorant treatment	Grain yield (t ha^{-1})		
		Inpara 1	Inpara 2	IR64
1	Without ameliorant	3.26	3.05	2.02
2	Farmer's method	4.10	3.90	2.75
3	Dolomite 2.0 t ha^{-1}	4.67	4.39	3.39
4	Rice straw 5.0 t ha^{-1} + *Eleocharis dulcis* 2.5 t ha^{-1}	4.77	4.41	3.43
5	Rice straw 5.0 t ha^{-1} + *Eleocharis dulcis* 5.0 t ha^{-1}	5.46	5.04	3.98

CONCLUSIONS

Acid sulphate soils (ASS) can be classified as marginal soils due to their limited carrying capacity for plant growth and production. Only certain types of plants are able to grow well in ASS. The rice cultivation technology that can be applied to turn ASS into a plant growth medium with economic value is a technology adaptive to the characteristics of ASS, accompanied by utilizing as much as possible the potential of the surrounding natural resources. This review provides a simple scientific overview based on the soil chemistry perspective behind the Banjarese-local rice cultivation system (BLRCS) practice. The BLRCS is capable of enabling local rice plants to grow and produce well in ASS due to the improvement of ASS soil properties during growing season. In BLRCS, rice cultivation schedule was arranged based on the land hydrological conditions and use local rice varieties with robust adaptability to extreme ASS conditions. In BLRCS, practices such as land preparation with tool *tajak*, organic matter (OM) management with the *tapulikampar* method and keep rice field in submerged condition during the growth stages of the rice plant are lead Fe solubility and soil pH becomes control and increase soil nutrients availability.

The lesson learned from the Banjar tribe who wisely manage ASS for rice cultivation is the essential of adapting the cultivation system to the seasonal characteristics of ASS. The rice cultivation system in ASS must consider the land hydrological conditions and utilize existing land resources. Proper water and OM management are essential factors for the success of rice farming on ASS.

Author contribution

Conceptualization: A.F., S.N., I.K., A.N. Methodology: A.F., S.N., I.K., A.N. Validation: A.F., S.N., I.K., A.N. Formal analysis, Investigation: A.F., S.N., I.K., A.N., R.D.N., N.Y., K.N. Resources: A.F., S.N., K.N., R.D.N. Writing-original draft: A.F., S.N., I.K. Writing-review & editing: A.F., S.N., I.K., A.N., R.D.N., N.Y., K.N. Visualization: A.F., S.N., R.D.N. All co-authors reviewed the final version and approved the manuscript before submission.

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