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WATER SCARCITY IN THE RICE FIELDS: A REVIEW ON WATER AND WEED INTERACTION IN THE LOWLAND RICE PRODUCTION AREAS

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ABSTRACT

Water management is important for rice production. Nowadays, water shortages frequently occur in many regions of the world due to competition between agricultural and industrial use of water resources and increasing climatic variability. It had impacts on industries and domestic uses, especially in agriculture; rice farming is the most affected. Factors such as herbicides efficiency and scarcity of water have contributed to the infestation of weeds in rice fields. Several factors such as climatic, edaphic, and biotic factors will determine the weed vegetation in particular areas. The different levels of water in the rice fields will favor different weed compositions. Under the saturated condition, grasses showed greater emergence while sedges grow rapidly when soil moisture was below saturation. Besides that, the rice grain yield was reduced more significantly under saturated conditions at 54% compared with 35% in flooded conditions, and thus creating great variation in the floristic composition of weeds. Therefore, good water management in rice fields needs to be emphasized to reduce weed infestation by selecting the appropriate weed control methods to increase rice production.
Keyword: Rice field, water shortage, weed infestation

Introduction

Rice (*Oryza sativa* L.) serves as a staple food in the daily dietnot less than 520 million of Asian population (Muthayya *et al.*, 2014), meeting the demand especially in the developing countries. However, the global rice demand is expected to increase by 60% in 2050 to accommodate the population growth (Fischer *et al.,* 2014). Since the early 1980s, it was observed that in some rice-growing areas of Asia there was continuous occurrence of rice yield reduction (Flinn & De Datta, 1984). Among the main factors is the scarcity of fresh water for irrigation. Supply of irrigation water to agriculture sector had been dropping significantly from 98% in 1900 to less than 80% in 2000 due toincrease demand from domestic, urban, and industrial sectors (Matloob*et al.*, 2015a; Tabbal *et al.*, 2002). Unfortunately, the acute water shortage coupled with increasing water crisis and time has threatened the sustainability of irrigated rice culture. Report from Tuong & Bouman (2003) stated that in 2025 approximately 20% out of75 million hectares of irrigated rice cropping areas in Asia will be affected by water scarcity.

Many studies and observations have revealed that weeds are among the major threats and serious biotic factors which limit rice grain yield (Ni *et al.*, 2000), possibly further reducing productivity of rice fields. Without proper weed control methods, weed infestation causes a loss of an average 10% of the total rice production (Wilhelm, 2004), an equivalent to US$30 billion annually (Beltran *et al.*, 2012). According to Azmi *et al.*, (2005), one of the parameters that cause rice yield to decrease drastically is the increase in weed infestations caused by limited water supply.

The occurrence of major shifts in weed populations involving perennial and annual, broadleaf weeds, sedges, grasses, and other types of weed species is usually observed in rice fields when there are rapid changes in rice establishment techniques and water availability. The increased incidences of weed community in rice fields are much higher after the introduction of direct seeding rice cultures. According to Juraimi *et al.* (2013), the factors in determining the degree of infestation and weed types encountered in rice often depended on rice ecosystems and establishment methods. Bhagat *et al.* (1996) and Matloob *et al.* (2015b) also explained that factors such as cultural practices (fertilizer and type of rice cultivar), rice cultaviation practice (irrigated, rainfed lowland, upland, deep water, or tidal wetlands), moisture regime (irrigated or rainfed), crop establishment (transplanted or direct seeded), and land preparation (lowland, upland, tillage, or no-till) influence the types of weed and severity of weed infestation in rice fields. Moreover, different water situations in rice fields may also determine the level of weed infestation and yield loss in rice, especially under reduced water conditions. As an example, the dominant rice weeds such as *Echinochloa crus-galli*, *Leptochloa chinensis*, *Fimbristylis miliacea*, *Cyperus iria*, *Cyperus difformis* and *Oryza sativa* L. (complex) (weedy rice) become widespread and dominant in direct seeded rice fields of Malaysia, especially in rice fields experiencing water scarcity (Hakim *et al.*, 2013)

Water Shortage Crisis in Rice Production

The agricultural sector plays an important role in food production across the world. However, since the early 21st century, the world population has increased steadily by three-fold, followed by competition with non-agricultural factors such as urbanization, industrialization, and economic development (Juraimi *et al.*, 2010), which has become a major threat to the progress of agriculture. On a more serious note, the food crisis is currently beginning to affect staple foods such as rice, especially in Asia. A study made by Serageldin (2001) estimated that 29 countries with a population of 450 million people will face severe water shortages. More concerning, a further increase of three billion people in 2025 would require an additional 20% of water to feed the population (Seckle r*et al.*, 1999).

The future of the agricultural sector is anticipated to be more challenging, especially when there is scarcity of fresh water resources. The agricultural sector is the major user of water resources; the agricultural irrigation systems use about 70% of the total water resources in a country. Water used for agriculture (including rainfall and irrigation) covers about 93% of the water resources worldwide. Arguably, the more significant one is the irrigated land which produces 40% of the total yield despite covering about 17% of the world cultivated land. In comparison, although the rainfall land covers about 83% of the global cropped land, it only produces about 60% of food production (Borlaug and Dowswell, 2000), showing that the irrigation is very important in global agriculture.

Water shortage for irrigation in rice fields initially occurred in certain countries but now has continued to rise and pose a threat to rice production globally. According to the FAO (2009), world rice production was 678.7 million metric tons of which about 90% comes from rice grown on 143 million hectares of land in Asia. The problems began to arise when the amount of fresh water decreases in most of the Asian countries between 1955 and 1990, where recorded the decline percentage around 40-60% (Gleick, 2003). However,the demand for rice is expected to increase by 60% by 2050 (Fischer *et al.,* 2014). The increasing world population causes the risingglobal rice demand. This situation is expected to worsen in 2035 when the rice production must increase by 26% from 2010 (Singh *et al*., 2014). Thus, to ensure food security in rice supply, farmers need to implement a strategic rice farming practice through the efficient use of resources such as water conservation, modernization of irrigation infrastructure, and responses to other global challenges.

Rice (*Oryza sativa* L.)

Rice plays an important role as a source of food and economy in Asia. Rice has the unique ability to grow in a wide range of hydrological situations, soil types, and climates. In fact, it can grow in wetland condition. Rice is grown worldwide, mainly in the lowlands under rainfed or irrigation in a shallow flood of the irrigated areas. Water requirement for rice is an integral component of food production. The average water requirement for irrigated rice is about 1240 mm per season (Yoshida, 1981). On the other hand, the water requirement for aerobic rice is lesser, ranging from 442-763 mm depending on the weather, topography of the farm, irrigation methods, and soil texture (Chan *et al.*, 2015).

Rice is a staple food and the most important crop in Asia. The global rice production is about 530 million tons per year with more than three billion consumers daily (35-60% calorie diet), making it as one of the major crops worldwide. More than 50% of the global rice is produced and consumed in China and India alone (Muthayya *et al.*, 2014) while the major rice producing countries are facing huge problems to meet the food demands of a growing population due to the climate change (flood and drought) and industrial development. The rapid economic growth and rising standards of living will increase the demand for rice. GRiSP (2013) reported that the global rice demand is expected to increase from 439 million tons (milled rice) in 2010 to 496 million tons in 2020 to 555 million tons in 2035. Singh *et al.* (2015) also supported the idea that annual rice production must increase by 26% over the next 25 years with an additional of 114 million tons in 2035.

Yield Loss Due to Weeds

Worldwide, the presence of the insect pests has caused rice yield losses of 40% while weeds have caused the highest loss of 32% (Rao *et al.*, 2007). Production of rice is experiencing losses due to weed problems in Asia, accounting as much as RM 88.9 million per season in 2004. Previous studies have proven that serious yield reduction occurs in Southeast Asia such as in Malaysia for 10-30% (Karim *et al.*, 2004), Vietnam for 10-45% (Chin *et al.*, 2000) and Thailand for 35-40 % (Tomita *et al.*, 2003). The threat of weeds which can cause yield losses is attributable to factors such as the type of cropping season, rice cultivar grown, planting distance, amount of fertilizer used, weed density, weed species, growth rate, duration and timing of weed infestation, management practices, and ecological and climatic conditions (Karim *et al.*, 2004).

Weed infestation can be problematic at any stage of growth, particularly in the first 45 days if there is no any control mechanism deployed. At the early growth stage, competition will determine the weed succession and rice yield losses, especially in the critical period of plant growth (Matloob *et al.*, 2015b). Consequently, under inadequate weed control, weeds always take over the rice planted during the first two months after sowing (Karim *et al.*, 2004).

Evidently, weed communities in direct seeded rice are richer in abundance than in transplanted rice. Reduction in yield can reach up to 48, 53 and 74% in transplanted, direct seeded in flooded conditions, and direct seeded in dry soils, respectively (Ramzan, 2003). The interference of weed and the losses of rice yield in direct seeded rice were 55% (Ampong Nyarko & De Datta, 1991) and uncontrolled weed species such as*Fimbristylismiliacea* alone had reduced grain yield by 42% (Begum, 2006).

Effects of Water Management on Rice Growth and Yield

Water management system is one of the key factors to ensure a high production of rice yield. There are two main aspects of water management in rice production which are irrigation and drainage. In Asia, 50% of the total freshwater in agriculture sector is being used to irrigate rice fields (Barker *et al.*, 1998; Tabbal *et al.*, 2002; Molden*et al.*, 2007). Water is a major constituent of tissue; an important reagent in the physiological and biochemical reactions; a solvent and carrier for mode of translocation for metabolites and minerals within a plant; and essential for cell enlargement through increasing turgor pressure (Farooq *et al.*, 2006). Studies have showed that water deficit affects rice growth (Farooq *et al.*, 2006). In the rice crop growth stage, the relationship between rice growth and yield productionis more sensitive during the reproductive stage than the vegetative stage (Bouman & Tuong, 2001).

Observations showed that the highest grain yield was in flooded condition compared to the continuously saturated condition (Ismail *et al.*, 2013; Juraimi, 2011). Rice yield reduction was found not significant if the water deficit was imposed during vegetative growth but up to 70% of yield deficit occurred when water was insufficient during the reproductive period (Lilley & Fukai, 1994). Rice yield was not significantly different between alternating submerged and non-submerged condition compared to continuous submerged but the former practice can reduce water usage by up to 15% without affecting the rice yield (Singh *et al.*, 2001; Belder *et al.*, 2004). Sariam (2004) and Juraimi *et al.* (2009) observed that rice yield was not significantly different between continuous flooding and intermittent flooding until the panicle initiation but produced higher rice yield than the continuous saturated condition. However, the results also showed that it was not necessary to continuously flood rice field during rice growing period to obtain high grain yield.

Observation by Ismail *et al.* (2013) found that the differences in grain yield under saturated conditions than the flooded conditions were marginally around 5%. Ismail *et al.* (2013) further suggesting that keeping the soil culture under saturated as water saving techniques for rice growth is comparable to the flooded condition with 50% less water consumption. Moreover, maintaining the saturated soil throughout the growing season can save up to 40% of water in a clay loam without reducing the rice yield (Srivastava *et al.*, 1989). However, Sariam (2004) recorded different results when the rice yield under saturated conditions was found to be significantly lower compared to yield under continuous flooded conditions.

Weed Infestation and Distribution in Rice Field

Weeds have a huge impact on plant growth and yield. Weed infestation is a serious biological threat which prevents the productivity of rice fields in both lowland and upland ecosystems and in all seasons (Ni *et al.*, 2000). For example, the nature of weedy rice such as fast growth; early reproduction; having heavy seeds that are rigid in the seed bank and in the soil for several years; and short lifespan allowing many generations in the growing season gives them an advantage over the desired plant species. Weeds are highly competitive against crops for space, carbon dioxide, light, air, moisture, and nutrients (Beard, 1973). Indirectly, weeds decrease water and soil temperature, further causing environmental problems such as blockage of canals and water pollution, and acting as a vector for pathogenic diseases and insect pests (Mercado, 1979).

Weed vegetation in a particular area is determined by several factors such as climatic, edaphic, and biotic factors. Basically, the meteorological conditions such as rainfall, temperature, and humidity are well related to the weed vegetation. In a given environment, the edaphic and biological factors are strongly affected by cultural practices such as soil structure, pH, nutrients and moisture status, associated crops, weed control measures, and field history especially in local geographical variations (Hakim *et al.*, 2010). Besides that, the abiotic factors such as irrigation, usage of fertilizer, cultivars grown, tillage, herbicide usage, and crop rotation could also affect the weed vegetation (Kim *et al.*, 1983).

Weed population distribution is a response to the ecological elements and human activities. However, management and environmental factors would always influence the performance of the distribution of weed (Juraimi*et al.*, 2013). Therefore, weed should be managed and controlled by a strategic planning to maximize the production of the crop and to ensure that the environment is maintained in order to avoid increasing crop production cost (Chauhan *et al.*, 2012). The main factors involved in the determinants of weed types and magnitude of their infestation are influenced by the type of rice culture, rice cultivation method, moisture regime, land preparation, and cultural practices. However, the dominancein weed species is mainly affected by water regime and type of rice culture (Drost, 1982; De Datta, 1981).

Estimated around 350 species comprising more than 150 genera and 60 plant families have been reported as rice weeds. Species of Poaceae or the grass family are the most common, with more than 80 rice weed species. The sedge family, Cyperaceae ranks second with more than 50 rice weed species. Other important weed families include Alismataceae, Asteraceae, Fabaceae, Lythraceae, and Scrophulariaceae. Distribution of weed communities is affected by variation in environmental factors (Juraimi*et al.*, 2013) such as soil, climate, altitude, culture techniques, invasive capacity of weed species, ecological and edaphic selection, and herbicide types (Chancellor and Froud-Willams, 1984; Hanafiah *et al.*, 1973).

Water Management and Weed Species

Weed species respond differently to changes in water regime (Bhagat *et al.*, 1999a). In the culture of rice, water and weeds are always considered closely related to each other. The dominance of grass and sedges is higher under the conditions of saturated and field capacity. Grases and sedges mostly occur in the saturated water level and partially occur alongside broadleaved weeds that are mostly present in the flooded water level condition (Aziz & Mansor, 2014). Broadleaved weed species *Monochoria vaginalis* and *Limnocharis flava* were dominant in soil submerged by water (Juraimi *et al.*, 2009) while under aerobic soil conditions, it was found that weed diversity, predominantly sedges and grasses was higher than the saturated or flooded condition (Anwar, 2011).

The type of weed species is associated with the soil moisture conditions or flooding depth (Begum *et al.*, 2006). *Echinochloa crus-galli, Echinochloa colona,* and *Leptochloa chinensis* are the more dominant weeds in the saturated and field capacity conditions (Juraimi *et al.*, 2011; Juraimi *et al.*, 2009). However, increasing the level of submergence hindered weed germination and reduced the weed population (Juraimi *et al.*, 2011). Begum *et al.* (2006) reported that the level of flooding depths of 5 cm for the durations of 14 and 21 days and at the onset of flooding within 14 DAS were effective in preventing the emergence and growth of *F. miliacea*. Similar results were observed by Tabbal *et al.*

(2002), who found that the weed growth was effectively suppressed when maintaining continuous shallow submergence during vegetative growth. However, shallow flooding and a shorter duration of flooding resulted in poor weed control (Begum *et al.*, 2006).

The abundance and growth of weeds in rice fields are also influenced by flood depth (Chauhan & Johnson, 2010). Williams *et al.,* (1990) in their study mentioned that flooding up to 10 cm suppressed germination of most weed seeds and killed the majority of weed seedlings. Similarly, it was found that the flood depth and longer submergence duration are very important, resulting in occurrence of strong inhibition of weed seeds germination of certain species especially grassy weeds (Begum *et al.*, 2006). The emergence percentage of *F. miliacea* was greatly reduced when flood levels at 5 and 10 cm depths were set for the durations of 14 and 21 days (Begum *et al.*, 2006).

Several studies have indicated that weed growth suppression can be achieved through water control (Rao *et al.*, 2007). Flooded conditions either continuous or alternate flooding suppress many weeds, while saturated and field capacity conditions encourage weed growth (Juraimi *et al.*, 2011). Aziz and Mansor (2014) reported that flooded conditions suppressed certain weed species germination in the seed bank. Bhagat *et al.* (1996) also reported that weed density is higher under reduced water conditions than submergence by about 70%. Tabbal *et al.* (1992, 2002) stated that continuous shallow submergence is a method that can effectively suppress weed growth, especially during vegetative growth. Studies found that weeds such as *Echinochloa*species, *L. chinensis*, *F. milicea,* and *Cyperacea*species are favorable in saturated water level condition (Aziz & Mansor 2014; Begum *et al.,* 2006). Juraimi *et al.* (2011) also reported that *F. miliacea* and *L. chinensis* grew poorly in saturated and field capacity conditions in the dry season.

Water Management and Herbicide Efficacy

Herbicides that provide excellent control when used in water can perform well in the absence of standing water. However, it is also evident that herbicides have responded differently to the weed population (Chauhan & Abugho, 2013; Kabir *et al.*, 2008; Bhagat *et al.*, 1999). Water management becomes more complicated when integrating herbicides with other control measures. The water level should be manipulated to increase the exposure of the weed leaf for some herbicides or to cover weed leaf for other herbicides. Therefore, herbicides application in wetland flood irrigation system may not be as effective in aerobic or saturated system (Anwar *et al.*, 2012). Previous studies have shown that the rice growth activity and susceptibility to herbicides are better in flooded than non-flooded. However, it is still poorly understood how the flooding improves the function of the herbicide (Baltazar & De Datta, 1992). Besides that, it is important to ensure that the herbicide in soil and water does not threaten the environment (Bayer & Hill, 1989; Patcharin *et al.,* 1988, Mahzabin & Rahman, 2017).

Herbicides and good water management are interdependent with each other. According to Smith (1967) good water management together with chemical weed control is the best measure to preserve soil moisture and reduce the production cost of rice. Herbicides can provide better weed control at all water depths, but the weed is less controllable in shallow water. In a field trial in Pulau Pinang, it was found that pendimethalinfollowed by (fb)bentazone/MCPA provided better weed control as compared to pretilachlor fb bentazone/MCPA in the off-season planting while the opposite result happened in the main season. The variation in weed control methods may be related to the difference in weed dominance between the seasons and the efficacy of herbicides in different soil moisture regimes (Juraimi *et al.*, 2010). Pre-emergence herbicides must be sprayed under shallow flooded conditions when herbicides are used to realize their full potential for weed control. Instead, rice fields following the application of post-emergence herbicides such as propanil should be completely drained for maximum contact with the herbicide.

It has been reported that the phenoxyl, 2-4D, and MCPA are effective to control sedges and broadleaved weeds as post-emergence application (15-25 days after transplanting). Butachlor and thiobencarb that control most annual grasses, broadleaved weeds, and sedgesare used as pre-emergence or early post-emergence (Chauhan *et al.*, 2014; Anwar *et al.*, 2012). Propanil is applied for post-emergence control of annual grasses, and some broadleaved weeds and sedges. Molinate suppresses *Echinochloa crus-galli*, but it is less effective on *Leptochloa chinensis* and *Ischaemum rugosum* (Azmi & Manshor, 1995). Appropriate as yield component indicator, Pretilachlor followed by bentazon/MCPA shows better broad spectrum weed control, increasing grain yields (Juraimi *et al.*, 2010).

Conclusion

Water is the best herbicide in lowland rice cultivation (Juraimi *et al.*, 2013). Each weed species has optimum soil moisture levels, providing different reactions between weeds and the rice crop. Therefore, a good water management in terms of depth, time, and duration of flooding is an important factor influencing effective weed control in rice.

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