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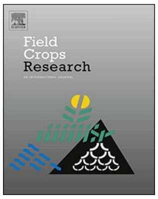

Improvement of yield, pest control and Si nutrition of rice by rice-water spinach intercropping

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ABSTRACT

Intercropping is an effective agricultural practice for crop production, resource utilization, and pest control. However, aquatic crops (e.g., rice) intercropping is relatively rare. Field experiments of two years/four seasons (early and late seasons in 2012, 2013) was carried out to test the effects of rice-water spinach intercropping on yield, disease and pest control, and Si, N nutrition of rice plant in the present study. The experiment contained three treatments including rice monoculture, water spinach monoculture and rice-water spinach intercropping with three replicates by randomized block design. Results showed that rice-water spinach intercropping significantly reduced the incidence of disease and pest of rice, with a reduction of rice sheath blight by 17.3%–50.6% and rice leaf folders by 5.1%–58.2%. For yield, intercropping resulted in an increase of rice yield by 45.1%–71.7% in early season and 20.9%–34.3% in late season, but a decrease of water spinach yield by 14.1%–37.1% in early season and 3.8%–18.3% in late season. However, rice-water spinach intercropping gave a higher land equivalent ratio (1.02–1.17) therefore improved land utilization efficiency. Furthermore, intercropping significantly increased Si concentration, Si and N absorption in rice leaves in ripening stage compared with rice monoculture. Our findings suggest that rice-water spinach intercropping exhibits yield advantage for rice or total yield, improves Si nutrition of rice and provides an environmentally sound approach in controlling disease and pest.

1. Introduction

Although industrial agriculture is advantageous in increasing labor efficiency and crop production, it also causes many problems, including biodiversity loss, soil fertility decline, non-point pollution aggravation from intensive use of fertilizers and pesticides, etc. (Boardman et al., 2003; Jacobsen et al., 2013). Intercropping is an agricultural practice of simultaneously growing two or more crops in the same field, which can efficiently utilize land, light, heat, nutrient, water and other natural resources (Andrews and Kassam, 1976; Vandermeer, 1990). This practice can increase biodiversity, productivity and stability of farmland ecosystem, showing advantages of economic and ecological benefits (Zhang and Li, 2003; Mushagalusa et al., 2008). It is attracting more attention for the development of sustainable agriculture.

To date, studies on intercropping focused on upland farming system, especially on cereal/legume intercropping, which poses the advantage of increasing total crop yield and improving nutrient status (Fujita et al., 1992; Chu et al., 2004). The main purpose of intercropping is to increase the productivity per unit of land. Rational combination of crops can use the available environmental resources efficiently and thus result in significant yield advantage (Vandermeer, 1990). The ways to achieve yield advantage of intercropping includes improving solar energy and nutrient efficiency, improving field microclimate, and enhancing the resistance ability, etc. (Banik et al., 2006; Javanmard et al., 2009; Liang et al., 2016). Zhang and Li (2003) indicated that interspecific and intraspecific competition exist simultaneously in intercropping system. However, interspecific competition should be weaker than intraspecific competition due to the relative dispersed niche, and this phenomenon will also help improve the overall yield of intercropping system.

Crop disease and pest control is one of the major agricultural activities to maintain high crop yield. Intercropping has an advantage of pest and disease control through breaking single crop planting structure and improving biodiversity (Lamondia et al., 2002). In rice, Zhu et al. (2000) and Han et al. (2016) found that different genotypic rice intercropping greatly reduced the incidence of rice blast compared with monoculture. Ren et al. (2008) reported that intercropping of watermelon and aerobic rice enhanced the resistance of watermelon to

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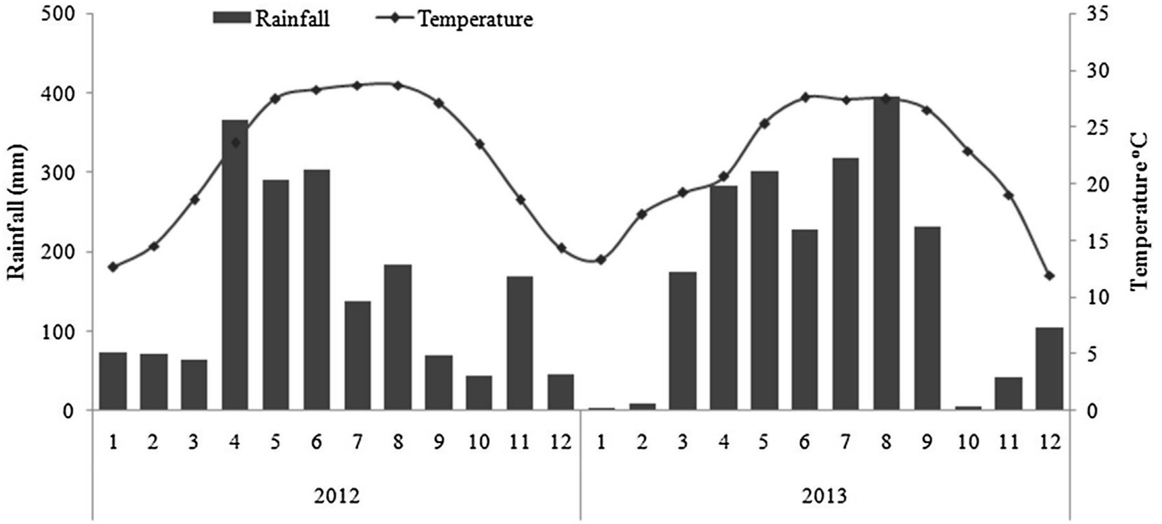

Fig. 1. Rainfall and average temperature per month during experimental years (2012, 2013). Numbers1-12 in the X axis represent the 12 months in a year.

Fusarium wilt. The mechanisms of intercropping to control pests are possibly attributed to physical barrier, dilution effect, non-lodged effect, allelopathy, microclimate change, etc. (Ratnadass et al., 2012). Furthermore, the increase of soil microbial diversity and activity in intercropping system is also a favorable reason for suppressing diseases and pests of crop (Borrero et al., 2004; Brussaard et al., 2007).

Improving soil nutrient use efficiency is another important advantage of intercropping. Intercropping crops can absorb nutrients from different soil layers because of the difference of root size, depth and nutrient demand, thereby improving soil nutrient utilization efficiency (Stoltz and Nadeau, 2014). Importantly, soil fertility under the intercropping system can be improved in a long-term period (Fujita et al., 1992; Ikerra et al., 1999). In general, intercropping promotes soil nutrient conversion by enhancing soil microbial activity, and then increases soil available nutrient content (Zuo and Zhang, 2009). In addition, root exudates can also increase soil nutrient availability, such as nitrogen and phosphorus (Li et al., 2007; Li et al., 2016). Currently, research on nutrients in intercropping system focused on nitrogen and phosphorus, as well as iron (Omondi et al., 2010; Xiong et al., 2013).

In paddy field conditions, aquatic crops (e.g., rice) intercropping is relatively rare. There were a few reports about rice intercropping with other crops (e.g., *Azolla*, water chestnuts, and water spinach), which highlighted the advantage of intercropping in increasing crop productivity and reducing disease incidence (Cisse and Vlek, 2003; Qin et al., 2013; Liang et al., 2016). Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world and the staple food of more than half of the world's population (Lu and Snow, 2005). Sheath blight (*Rhizoctonia solani*) and leaf folder (*Cnaphalocrocis medinalis* Guenee) are common pests and diseases of rice. Rice sheath blight is caused by *Rhizoctonia solani* Kühn, which is a stubborn soil habitat fungus. The disease incidence is related to not only the initial fungi amount, but also field microclimate and plant traits. High temperature and humidity are the main external causes of the disease, while aeration and permeability can reduce mycelial growth (Yuan et al., 2004). Rice leaf folder belongs to Lepidoptera, and it destroys rice through larva feeding on rice leaves that rolled up (Han et al., 2015). The incidence degree of leaf folder is mainly affected by the number of adults that move into the field and climatic conditions.

Furthermore, rice is a typical silicon-accumulating crop, with an average Si content of up to 10% in plant tissues (Ma and Takahashi, 2002). Silicon can strengthen plant defense against abiotic stresses (i.e., heavy metals, salinity, and drought) and biotic stresses (i.e., attacks by pests and pathogens), thereby improve the yield and quality of rice (Ma et al., 2001; Guntzer et al., 2012). A large number of studies have verified that exogenous Si could enhance plant resistance against diseases and insects, the resistance mechanisms mainly include: (1) physical barrier: silicon deposition in plant tissue impedes the attack of pests (Winslow et al., 1997; Massey and Hartley, 2009); (2) induced resistance: silicon can increase the defense-related enzyme activities and induce the accumulation of antifungal compounds of plant tissue (Fauteux et al., 2005); and (3) molecular mechanism: silicon can induce the expression of gene or protein associated with plant defense (Rodrigues et al., 2005; Liu et al., 2014). In general, total silicon content is high in soil as it is the second most abundant element in the earth's crust. However, soluble silicon that can be absorbed by rice is limited (Sommer et al., 2006). Continuous rice cultivation results in the shortage of soluble silicon in paddy soil, especially in highly weathered tropical areas (Tsujimoto et al., 2014; Marxen et al., 2016). To the best of our knowledge, no reports are available about silicon absorption and utilization in intercropping system. Water spinach (*Ipomoea aquatic* Forsk) is an important aquatic vegetable in southern China, with shallow root distribution and strong regenerative capacity. When rice is intercropped with water spinach, it is interesting to know if there are beneficial impacts on Si absorption of rice plant, which may bring positive influences in rice production.

In the present study, field trials of two years/four seasons (early and late seasons in 2012 and 2013) with rice and water spinach intercropping were conducted to determine the effects of intercropping on: (1) yield and land production efficiency, (2) disease and pest control, and (3) Si and N nutrition of rice. This study will help explore an environmentally sound and economically feasible approach for rice sustainable cultivation.

2. Materials and methods

2.1. Study site

The site of field trials was located in the rice farm in South China Agricultural University (113°21′E, 23°9′N), Tianhe District, Guangzhou, Guangdong Province, China. This area has a subtropical monsoon climate. The annual average temperature is 21.9 °C and rainfall is 1647.5 mm. The rainfall and average temperature per month during experimental years are shown in Fig. 1. The basic physical and chemical properties of the soil for field experiments are as follows: pH 5.54, 20.28 g kg^{-1} organic matter, 1.24 g kg^{-1} total N, 0.53 g kg^{-1} total P, 10.21 g kg^{-1} total K, 6.45 mg kg^{-1}ammonium N, 4.78 mg kg^{-1}nitrate N, and 167.88 mg kg^{-1} available Si.