Global Food Security 18 (2018) 62–75

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Research article

The implications of red rice on food security☆

Alvaro Durand-Morat[a,*], Lawton Lanier Nalley[a], Greg Thoma[b]

[a] Dept. of Agricultural Economics & Agribusiness, University of Arkansas, AGRI 217, Fayetteville, AR 72701, United States
[b] Bates Teaching Endowed Professorship in Chemical Engineering, Ralph E. Martin Dept. of Chemical Engineering, University of Arkansas, BELL 03153, Fayetteville, AR 72701, United States

ARTICLE INFO

Keywords:
Rice
Weedy rice
Food security
Life Cycle Assessment

ABSTRACT

Due to its genetic similarity with commercial rice, red rice is one the most damaging weeds in direct seeding rice systems. Using an integrated approach to estimate the economic, environmental, and food security impact of red rice infestation in the U.S. as an empirical case study, we find that losses under a moderate infestation scenario from 2002 to 2014 amount to 5.7 million tons or 6%, with an environmental cost of $457 million. The resulting production loss in the U.S. is enough to feed 12 million additional people a year. We extend these findings to selected Asian countries where adoption of direct rice seeding is increasing, and estimate that red rice can have significant impacts on global food security.

1. Introduction

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population, with the majority located in rapidly growing low-income countries (Maclean et al., 2013). Globally, rice production largely supports local domestic markets, with approximately only seven percent of total rice traded internationally, with five countries (India, Thailand, Vietnam, Pakistan, and the United States) accounting for 80% of total rice exports since 2014 (USDA, 2018). The thinly traded nature of the global rice market means that even a mild shock to rice supply in the major rice exporting countries could lead to significant implications on global food security. For instance, the World Bank estimated that the implementation of a rice export ban by India, Vietnam, and Cambodia in 2007 (causing a global price spike) resulted in an additional 105 million people being pushed into poverty (World Bank, 2013). Despite causing such a significant disruption, the price increase occurred with only eight percent reduction in trade (Childs, 2009). In addition to economic repercussions, supply shocks can also manifest themselves in the form of environmental and biotic challenges. For instance, in the 2017/18 rice season, Bangladesh experienced significant losses due to a combination of floods and localized pest problems, which led to a 50-percent price increase in the domestic market relative to 2016/17 and an expansion of rice imports of around one million metric tons (USDA, 2017). Likewise, a severe drought in Sri Lanka in 2017/18 decreased production and led to rice price increases of over 20% (FAO, 2017).

Red rice was declared a problem in the United States in the early 20th century and is now the most prevalent weed problem rice producer's face in the Lower Mississippi Delta Region (LMDR) consisting of Arkansas, Louisiana, Missouri and Mississippi. Because red rice and cultivated rice descended from a common ancestor, both are genetically similar and can interbreed at low rates as red rice is primarily self-pollinated (Langevin et al., 1990; Gealy et al., 2000; Lu and Snow, 2005; Londo and Schaal, 2007). Because weedy traits are dominant, the offspring of weed–crop hybrids are generally weedy plant types only increasing the weed pressure on monoculture rice production in the United States (Burgos et al., 2006). There is a large variability within each red rice type in terms of canopy structure, height, tillering capacity, leaf size, flowering date and seed yield. This is of immense practical importance because it indicates that genetic introgression between cultivated and weedy plants has increased the diversity of weedy red rice in the United States making its control more difficult once a seed bank has developed (Shivrain et al., 2010). Once established in fields it has been shown that red rice in the United States may take up 60% of total applied N resulting in up to 80% decrease in cultivated rice yields (Burgos et al., 2006). Red rice remains a problem in the United States despite vigorous efforts to eliminate it because of its close genealogical resemblance to cultivated rice, because of the fact it shatters easily which increases its seedbank, the viability and longevity of its seedbank and the fact that rice production is relatively profitable to alternative crops in the LMDR (Burgos et al., 2008).

Around 90% of global rice is produced in Asia, where transplanting (seedlings are first raised in seedbeds before they are planted in the

☆ This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

* Corresponding author.
E-mail addresses: adurand@uark.edu (A. Durand-Morat), llnalley@uark.edu (L.L. Nalley), gthoma@uark.edu (G. Thoma).

https://doi.org/10.1016/j.gfs.2018.08.004
Received 23 April 2018; Received in revised form 27 July 2018; Accepted 6 August 2018
2211-9124/

main field), predominantly by hand, continues to be the dominant production method (Rao et al., 2017; Rao and Ladha, 2013). Traditionally, transplanted rice crops are weeded by hand, sown with seedlings, and maintained flooded throughout the crop. These practices help to suppress weed, including red rice, competition and reduce weed driven yield losses (Chauhan, 2013; IRRI, 2000). As labor resources in low-income countries, particularly in Asia, become increasingly scarce or prohibitively expensive (increased agricultural labor prices due to migration from rural to urban areas), rice producers across major producing areas in Asia (the Central Plain in Thailand and the Mekong Delta region in Vietnam) are adopting the less labor intensive direct seeding method (seeds are sown directly in the field) (Singh et al., 2013; Chauhan, 2013; Chauhan et al., 2015). Historically, crop establishment with direct seeding requires less labor and is more amenable to mechanization than transplanted rice (Chauhan, 2013). However, direct rice seeding does not offer the weed suppression advantages that transplanted rice does, which exposes producers to new production risks in the form of weed competition and potential yield losses.

Red rice is one the most prevalent and damaging weed problems in direct seeding rice systems like in the United States (Delouche et al., 2007), and the shift from transplanted to direct-seeded rice can exacerbate the global red rice problem in Asia (Ziska et al., 2015; Kraehmer et al., 2016). Red rice is problematic primarily because it competes with cultivated rice for light and nutrients. Red rice has greater N use efficiency (Burgos et al., 2006), produces more tillers and shatters most of its seeds earlier than cultivated rice (Estorninos et al., 2005), and can over winter at rates from 60% to 90%, compared to 5% for cultivated rice (Baek and Chung, 2012). Given these attributes, once red rice appears in a cultivated rice field, its ultimate eradication can be costly, time-consuming, and difficult.

Recent studies have detailed diverse biological relationships among global red rice types, including varying flowering times, tillering and hull characteristics (Gealy et al., 2005, 2006). A recently identified red rice in California appears to be genetically distinct from red rice in the Southern U.S. (Londo and Schaal, 2007). Because of the possibility that genes have introgressed between different red rice populations or between rice cultivars and red rice populations there are distinct differences in red rice types based on the local rice varieties planted (Gealy et al., 2009). As such, the genetic makeup and potential yield losses between Asian and American red rice types can vary slowing global herbicide research to mitigate red rice yield losses.

Because physiologically and morphologically red rice resembles cultivated varieties, current herbicides used in rice production which can control red rice also damage rice cultivars, making the chemical control of red rice on conventional rice fields challenging (Sudianto et al., 2013). Until the release of Provisia rice in the U.S. in 2018, Clearfield® (CL) was the only chemical herbicide available to selectively eliminate red rice from commercial rice fields. CL rice was obtained through induced mutation in the genes that synthesize the acetolactate synthase (ALS) enzyme, making it tolerant to imidazolinone (IMI) herbicides. Thus, IMI herbicides inhibit the production of ALS in non-CL varieties and red rice but not in CL varieties, thus serving as an effective red rice management tool (Tan et al., 2005). When it was introduced, the CL technology provided 95–100% red rice control (Avila et al., 2005; Levy et al., 2006; Ottis et al., 2004; Steele et al., 2002). The adoption of CL rice varieties to control red rice grew in the U.S. since its release in 2002, reached 650,000 ha or 40% of the area planted to long grain rice in 2010, and has remained at about 40% since. The management practices followed on other 60% (non-CL rice) area to control red rice include the use of certified seeds, off-season herbicide burn downs, water seeding (in California and parts of southern Louisiana), and crop and herbicide rotation. However, increasing red rice cases are being reported in California where no CL medium grain rice (the predominant rice type in California) is available. Outside the U.S. Brazil is the largest CL rice adopter globally with 710,000 ha in 2015–2016 (IRGA, 2016).

Red rice can decrease both grain yields and quality (Ottis et al., 2005; Delouche et al., 2007). Rice yield losses associated with red rice infestations vary by rice variety (Eleftherohorinos et al., 2002; Kwon et al., 1991; Diarra et al., 1985; Ottis et al., 2005), red rice ecotypes (Estorninos et al., 2005; Shivrain et al., 2009), red rice density (Estorninos et al., 2005; Ottis et al., 2005), and the duration of the interference (Shivrain et al., 2009; Smith, 1988). Reported yield losses due to red rice infestations vary based on the combination of these variables. Chin (2001) reports yield losses of 16% in Vietnam; Kwon et al. (1991) estimate yield losses ranging from 27% to 45% in the U.S., and Azmi and Karim (2008) report yield losses ranging from 60% to 100% in Malaysia. Red rice infestation can ultimately lead to the abandonment of rice fields due to the prohibitively high yield losses (Delouche et al., 2007).

Global rice consumption is projected to continue to increase in the next decade (Timmer et al., 2010), and the only way to meet the demand at the current global average rate of yield growth is through a significant expansion in rice area (Ray et al., 2013). The expansion of direct-seeded rice may result in productivity and economic losses if crop management practices are not adjusted to account for the potential increase of red rice infestations. Productivity losses due to red rice infestations can potentially reduce global rice supplies and increase global price volatility, which can ultimately undermine the progress made by plant breeders, and other rice scientists in their effort to combat food insecurity.

This study analyzes the impact of red rice infestation on the global rice prices and food security by focusing on the Lower Mississippi Delta Region (LMDR) of the U.S. as an empirical case study. We develop a counterfactual scenario in which we simulate the removal of the CL rice technology that mitigates the impact of red rice and estimate the economic and environmental impact of red rice by comparing the counterfactual against actual observed market outcomes. We estimate the impact of red rice infestation on 1) on-farm yields, 2) regional and global rice supply, 3) environmental costs of rice production, and 4) consumer welfare/food security. From these results, we estimate the impact that rice producers in China, India, and Vietnam may face as they adopt direct seeding rice and the potential introduction of red rice. The results of this study will give agricultural scientists an estimate of what the impact of red rice could be if not controlled through proper management, including the use of CL rice.

2. Methodology

2.1. Estimation of yield loss associated with red rice infestation

Several existing models estimate cultivated rice yield loss as a function of levels of red rice infestation (Vidotto et al., 2001; Ottis et al., 2005; Zhang et al., 2014). We emulate Zhang et al. (2014) methodology because unlike the model put forth by Ottis et al. (2005), which focuses on the differences between hybrids and inbred varieties, and that by Vidotto et al. (2001), which was based on a semi-empirical non direct seeding model, Zhang et al. (2014) is empirical in nature and appropriate for direct dry seeded conditions. Zhang et al. (2014) yield loss function is described as

$$YL_t = 7.122M_t^{0.576}, \tag{1}$$

Where YL_t represents the percentage rice yield loss and M_t is the density of mature red rice per square meter in year t. Following Zhang et al. (2014), we dynamically model M_t as a function of the initial red rice seed bank in year t that germinates and survives competition. The contribution of mature red rice plants in year t to the initial seedbank in year $t+1$ is a function of the shattering rate, the number of seeds produced per red rice plant, and the dormancy rate. The initial seedbank in year $t+1$ equals the contribution of new red rice seeds in year t and the proportion of seeds in the initial seedbank in year t that develop