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Economic implications of herbicide resistance and high labour costs for management of annual barnyardgrass (*Echinochloa crus-galli*) in Philippine rice farming systems

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ABSTRACT

Implications of increasing labour costs and the development of herbicide resistance for profitable weed management in Philippine rice farming systems are investigated. The study employs RIMPhil (Resistance and Integrated Management in the Philippines), a bioeconomic simulation model developed to provide a comprehensive assessment of integrated weed management programmes for the control of annual barnyardgrass (*Echinochloa crus-galli*) in rice crops. Results indicate that herbicide application will become increasingly economically attractive, relative to manual weeding, as labour cost increases. This is important since urban migration in the Philippines continues to increase the scarcity of rural labour. Results also show that the onset of herbicide resistance results in substantial losses in farm profit. It is worthwhile for farmers to take management actions to prevent or delay the onset of herbicide resistance, provided that these changes are effective and not too costly. The study highlights the complexity of decision making about integrated weed management on rice farms in the Philippines.

1. Introduction

Rice is the staple food of more than 3 billion people worldwide, but growth rates in crop yields have fallen in recent times, declining by 82 per cent in 1991–2006, relative to the previous 15 years (Van Nguyen, 2009). Moreover, there is extensive evidence that environmental degradation (Pingali et al., 1997) and scarcity of appropriate land (FAO, 2002) and water resources (Rosegrant et al., 2002) are becoming increasingly important in limiting the capacity of rice production to meet global demand, which is expected to double by 2050 (Van Nguyen, 2009). This highlights a key need to promote the efficient production of rice within existing farming systems.

Manual weeding and flooding are traditionally used to restrict weed competition in rice farming systems. However, there has been a growing reliance on herbicides. Herbicide sales for rice crops globally grew at an average rate of more than 2 per cent year^{-1} from US$741 million in 1980 to US$1.34 billion in 2007 (Norton et al., 2010), exceeding growth rates reported for sales of insecticides (0.9 per cent year^{-1}) and fungicides (0.2 per cent year^{-1}). The global sale of herbicides for application in rice farming systems could reach US$3 billion year^{-1} by 2025 (Zhang et al., 2004). The trend in the Philippines from transplanting to direct-seeding rice has promoted the shift to herbicides, as initial flooding is not possible to control weeds in direct-seeded rice (Baltazar and De Datta, 1992). In addition, broadcast seed does not grow in consistent rows, making manual weeding less efficient (Marsh et al., 2005). Herbicides are easy to use, can achieve high rates of control with effective application, and are, overall, relatively inexpensive. On the other hand, the long-term economic benefits of alternative means of weed control can be influenced by a variety of factors, including labour costs.

Wage rates for farm workers in the Philippines have been increasing steadily over the last two decades (BAS, 2011). An important factor contributing to this increase has been the migration of farm workers, mostly unskilled, from agricultural to non-agricultural sectors (Habito and Briones, 2005). Indeed, in some areas of the country (e.g. Laguna and Bulacan), many farmers are finding it increasingly difficult to hire seasonal workers, resulting in higher farm workers' wage rates (Moya and Dawe, 2006). Higher labour costs could greatly influence the management decisions of producers, particularly those concerning the trade-off between the use of manual weeding and herbicides for weed control.

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Many studies have found that the onset of severe herbicide resistance in important crop weeds results in substantial economic losses (e.g. Pannell et al., 2004; Jones et al., 2006; Doole et al., 2009) This has been observed the world over, particularly in developed countries such as Australia and the United States of America (USA). The negative impacts of herbicide resistance in rice farming systems throughout developing countries, such as the Philippines, have thus far arguably been reduced since manual weeding can still be a profitable alternative to herbicide application. Nevertheless, the superiority of manual weeding is conditional on maintaining low levels of weed density in every cropping season and on sufficiently low labour costs. Moreover, a mechanical weeder can also be used as a substitute for herbicide application and manual weeding, although this method is typically less effective and requires row planting to facilitate its use.

High weed populations are commonly observed on most Philippine rice farms. With an increasing cost of labour, economic theory indicates that there is likely to be increased demand for substitute methods of weed control, such as herbicide application. Increasing herbicide use will promote the onset of herbicide resistance in rice farming systems, which could have a large adverse effect on farm income. Incidences of 2,4-D-resistant *Sphenoclea zeylanica* (Sy and Mercado, 1983) and butachlor + propanil-tolerant *Echinochloa crus-galli* (Juliano et al., 2010) have been reported in some important rice areas in the Philippines. Furthermore, in Central America, populations of propanil-resistant *Echinocloa colona* have been documented on many rice farms (Valverde et al., 2000). The objective of this study is therefore to investigate the impacts of increasing labour cost and the potential development of herbicide resistance on profitable strategies for the long-term management of weeds in rice farming systems. A simulation model of a representative rice farming system of the Philippines (Beltran et al., 2011) is used to investigate these problems within the context of the management of annual barnyardgrass (*Echinochloa crus-galli*), one of the most serious weed competitors of rice crops in the Philippines (Graf and Hill, 1992; De Dios et al., 2005). The model is based on an assumption that weeds other than annual barnyardgrass are controlled sufficiently in the field, which means that only two species of plants (i.e. rice and barnyardgrass) are competing for the limited resources. Where multiple weeds are present at high densities, results of the model would not be applicable. A modelling approach is highly appropriate given the inherent complexity of weed management decisions, particularly considering their dynamic nature and the integrated nature of many effective control strategies. A feature of this analysis is the use of extensive sensitivity analysis to assess how model output changes with perturbations to key parameters.

The aims of the paper are to evaluate the impacts of increasing labour cost and build up of herbicide resistance on the composition and profitability of alternative long-term weed management strategies in Philippine rice farming systems. It is structured as follows. Section 2 describes the model used in the analysis. The results of the analysis for labour cost are presented and discussed in Section 3, while those for herbicide resistance are presented and discussed in Section 4. Section 5 concludes the analysis.

2. Tools and methods

2.1. Model outline

The study employs the RIMPhil (Resistance and Integrated Management in the Philippines) model. This complex model is described in detail in Beltran et al. (2011) and readers are referred to this source for more information. RIMPhil is a bioeconomic model, embedded in a decision support system (DSS), developed to analyse the economics of integrated weed management strategies for rice farming in the Philippines. It allows the analysis of strategies to control annual barnyardgrass, both in the presence and absence of herbicide resistance. The structure of the RIMPhil model is loosely based on that of the RIM (Resistance and Integrated Management) model, which has been developed in Western Australia to guide the management of annual ryegrass (Pannell et al., 2004) and wild radish weeds (Monjardino et al., 2003) in extensive mixed farming systems based mainly on cereal crops and livestock.

RIMPhil is a deterministic, dynamic model that allows the simulation of management strategies over a 20-year period. The incorporation of multiple years helps to describe the dynamic nature of weed populations and resistance development in a meaningful way. No automated optimisation procedure is used to identify the most profitable strategies, as done, for example, by Doole et al. (2009). Rather, a broad range of possible weed-control strategies is evaluated through an extensive process of manual “trial and error” to identify near-optimal solutions. The preferred strategy is selected on the basis of producing the highest profit over the 20-year period defined in the model.

2.2. Weed-crop competition

In the RIMPhil model, the impacts of a rice crop’s competitive ability on the number of seeds produced (seeds m^{-2}) per barnyardgrass plant (S_{WP}) is captured in the following equation:

$$S_{WP} = S_{MS} \times \left(\frac{1}{a + W_{HB} + (b \times D_{DC})}\right) \times \frac{W_{HB}}{W_{WS}} \times (1 - D_E), \quad (1)$$

where S_{MS} represents maximum barnyardgrass seed production (seeds m^{-2} season^{-1}), a signifies the barnyardgrass background competition factor (BBCF) that is used to calculate the base level of intraspecies competition affecting weed seed production, W_{HB} refers to the healthy equivalent barnyardgrass population density (plants m^{-2}) before harvest, b is the rice crop competition factor on barnyardgrass (RCFB), D_{DC} refers to the rice crop density depending on the seeding rate selected in the model, W_{WS} is the number of barnyardgrass (plants m^{-2}) surviving all of the treatments that occur before harvest, and D_E represents the sub-lethal effect of selective herbicides that leads to lower seed production by weeds. The parameter values used in the model are as follows: $S_{MS} = 48{,}000$, $a = 23$, and $b = 0.6/0.3$ for transplanted/direct-seeded rice, respectively.

Rice yield depends on the crop density and the competitive abilities of rice relative to barnyardgrass across planting techniques (Kropff and Lotz, 1993). In this model, assumed values used for standard crop yields are 5 t per hectare (ha) for wet season and 6 t ha^{-1} for dry season. These values are the maximum attainable yields for certified inbred rice varieties in both seasons within a rice field with adequate fertility and no problems with water supply (Balisacan et al., 2006). The proportion of weed-managed yield that exists after accounting for the yield loss due to weed competition (Y_{PR}) is calculated using:

$$Y_{PR} = \frac{1+c}{D_{SR}} \times \left(\frac{D_{DC}}{c + D_{DC} + (d \times (W_{WS} + W_{WA}))}\right) \times M_{YL} + (1 - M_{YL}), \quad (2)$$

where c refers to the rice crop background competition factor (RBCF), D_{SR} represents a standard reference rice crop density (plants m^{-2}) for each planting method, D_{DC} refers to the actual rice crop density (plants m^{-2}) that depends on the seeding rate selected by the user, d signifies the barnyardgrass competition factor in the