

## **O.32 - Implications of the second-best decisions in weed control under social constraints: a case of wheat farming in Japan**

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### **Abstract**

Optimum crop protection strategies are not always feasible because of social constraints. For example, paddy-upland rotation, which is a common weed control and soil fertility management method in Japan, is not always practiced. When group decisions on cooperative land rotation that were undertaken to comply with government policy on reducing rice production have failed, rotation of upland wheat, upland soybean, and fallow is practiced. This is necessary because the location of paddy cultivation must be in one place, which makes rotation of paddy rice, upland wheat, upland soybean, and fallow unfeasible. In this case, farmers have to employ weed control methods other than paddy flooding which can be considered as ecological weed management. However, potential weed control options are limited to, for example, application of herbicides and lime, which are not necessarily effective because of the existence of herbicide-resistant weeds. Furthermore, increased use of herbicides tends to increase environmental degradation as well as economic costs. Thus, farmers are forced to make the second-best (suboptimum) decisions. This paper defines the second-best decisions made under social constraints by constructing a decision making structure on weed control for wheat cultivation in Japan. Two-objective decision models, which are presented graphically using influence diagrams, are developed for the analysis. The results indicate that under social constraints, farmers are forced to make the second-best decision, in which they cannot apply paddy flooding as ecological weed management for reducing the use of herbicides, and that the suboptimum decision affects the environment as well as the economy.

### **Introduction**

Optimum crop protection strategies are not always feasible because of social constraints. For example, paddy-upland rotation, which is a common weed control and soil fertility management method in Japan, is not always practiced. When group decisions on cooperative land rotation that were undertaken to comply with government policy to reduce rice production have failed, rotation of upland wheat, upland soybean, and fallow is practiced. This is necessary because the location of paddy cultivation has to be fixed, which makes rotation of paddy rice, upland wheat, upland soybean, and fallow unfeasible. In such cases, farmers have to employ weed control methods other than paddy flooding which can be considered as ecological weed management.

However, weed control options available to farmers are limited to, for example, application of herbicides and lime, which are not necessarily effective because of the existence of herbicide-resistant weeds. Furthermore, increased use of herbicides tends to increase the cost and result in environmental degradation. Thus, farmers are forced to make the second-best (suboptimum) decisions.

This paper defines the second-best decisions made under social constraints by constructing a decision making structure on weed control for wheat cultivation in Japan. The difference between individual decisions and cooperative decisions regarding weed control and the losses caused by suboptimum decisions are also discussed.

### Effects of paddy flooding on weed emergence in wheat production

One of the important characteristics of this weed management system is that it is practiced within a rotation series and is, therefore, different from flooding, which is used to suppress perennial weeds before or after periods of crop production (Liebman, Mohler and Staver, 2001). To clarify the effectiveness of paddy flooding in preventing the emergence of Italian ryegrass in wheat production fields, field observation data were collected using category estimation procedures in Shizuoka Prefecture, Japan. The results indicate that weed density in wheat fields after paddy rice cultivation is clearly lower than that after soybean production or fallow (Kida et al, 2007).

### An expository analysis using two-objective decision models for weed control

In order to construct integrated models for weed control decisions with multiple decision options and objectives, influence diagrams were used for analysis. Two models were developed: Model A explains the influence of a decision variable (the level of herbicide application) on two objective variables (the yields of wheat and human toxicity measured by disability adjusted life years, DALYs); and Model B illustrates the decision with two decision variables (the level of herbicide application and whether to conduct paddy-upland rotation) and two objective variables (crop yields and human toxicity). These are two-objective models because their objectives are to maximize crop yields and to minimize human toxicity.

A yield (response) function, which maps management intensity per unit area onto crop yields per unit area, is used as a basic model to evaluate the influence of decision variables on the objective variable (crop yields) as shown in Fig. 1. Model A uses a yield function for illustrating the relationship between the intensity of herbicide application (herbicide dose as a decision variable) and crop yields (the objective variable). The yield function is constructed based on the relationship between initial weed density and crop yields, which is defined using a rectangular hyperbola. The general response curve for the  $i^{\text{th}}$  herbicide dose is defined as follows:

$$y = y_0 / (1 + \beta_i w_0)$$

where  $y$  = crop yields,  $y_0$  = weed-free crop yields,  $\beta_i$  = the competitiveness of the weed (a weed density of  $1/\beta_i$  will reduce the crop yields by 50%), and  $w_0$  = the initial weed density. For a crop grown at a single density, the initial weed density yields an objective measure of the potential amount of weed present later in the season. If we assume that the relationship between herbicide dose and weed biomass is well described by the standard dose-response curve, then the change of parameter  $\beta_i$  with herbicide dose can also be modeled using the standard dose-response curve as follows (Kim et al., 2002):

$$\beta_i = \beta_0 / \left( 1 + \left( \frac{d_i}{e^{\text{LD}_{50}}} \right)^B \right)$$

where  $\beta_0$  = weed competitiveness at no herbicide treatment,  $d_i$  = the  $i^{\text{th}}$  herbicide dose,  $\text{LD}_{50}$  = the log of the dose required to reduce weed competitiveness by 50%, and  $B$  = the response rate or steepness of the curve. In Model B, an additional decision variable (a binary variable  $p$  that shows whether the paddy-upland rotation is conducted or not) is included. The value for  $w_0$  is determined using the observation that the rate of yield reduction of 5% after paddy and 70% after soybean (or fallow).

An impact function, which maps management intensity per unit area onto an environmental impact per unit area, is used for estimating the influence of the decision variable on the objective variable (human toxicity) and is defined as follows:

$$z_i = \text{HDF}_i d_i$$

where  $z_i$  = the environmental impact (human toxicity) for a given substance  $i$  (herbicide dose) and  $\text{HDF}_i$  = the human damage factor in DALYs per loading (Humbert et al. 2007).

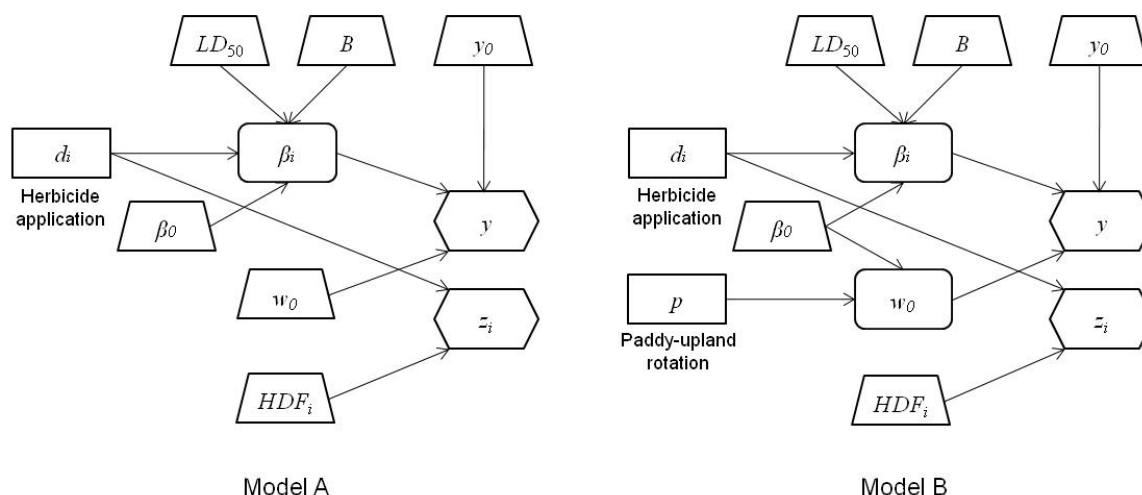


Fig. 1. Influence diagrams for weed control decisions.

An example of the calculation based on the models is shown in Fig. 2. If we follow the decision rule of selecting the least application level of herbicide dose that attains maximum possible crop yields (lexicographic optimisation), we have two solutions for each value of  $p$ . One is the best decision which corresponds to the case of wheat cultivation after paddy rice and the other is the second-best decision which corresponds to the case after soybean or fallow. The result shows that under social constraints, farmers are forced to make the second-best decision, in which they cannot apply paddy flooding as ecological weed management that greatly reduces the use of herbicides.

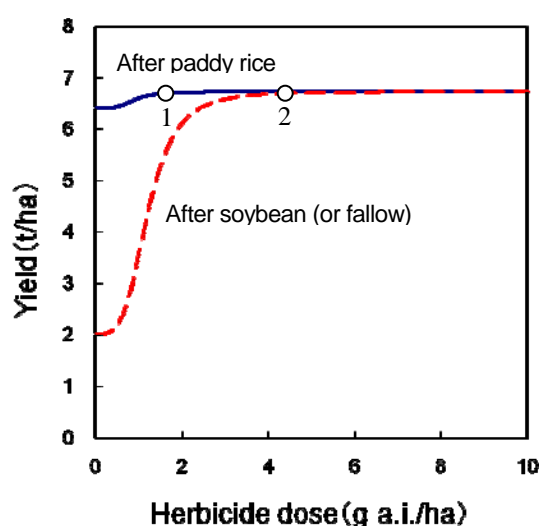


Table 1. The best and second-best decisions.

	The best decision (1)	The second-best decision (2)
$y$ (t/ha)	6.70	6.70
$z_i$ (DALYs/ha)	$5.14 \times 10^{-11}$	$1.44 \times 10^{-10}$

Note: A 99.5% yield level is regarded as the maximum value. The damage factor ( $3.21 \times 10^{-8}$  DALYs/kg) is taken from IMPCAT 2002+.

Fig. 2. Yield responses predicted by Model B (an example): 1 = the best decision; 2 = the second best decision.

## Discussions: Implications of the second-best decisions

An important difference between the two decision variables is that herbicide application is classified as individual decision making and paddy-upland rotation as group decision making. Therefore, consensus building among farmers is necessary to implement paddy-upland rotation. Thus, the practice of inappropriate rotations (suboptimum decisions) results from a failure of making group decisions.

This failure greatly affects the society. It necessitates applying additional herbicides to reach the same yields as wheat production after paddy rice cultivation. Therefore, inappropriate rotation entails excessive application of herbicides, which results in human and environmental toxicities. The excessive use also causes economic losses to farms as well as society.

The discussions so far are based on the assumption that herbicide application is considered effective. However, it is difficult to make decisions when weed species and genotypes develop resistance or tolerance against the herbicides. In such cases, farmers lose incentives to maintain wheat production because of the significant decrease in farm profitability.

## Conclusions

This study suggests that social constraints make weed control decisions suboptimum and that the failure in making a group decision affects the environment as well as economy. These results imply that crop protection decisions are closely related to social systems and therefore these decisions have to be analysed as resource management according to socio-technical systems.

## References

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