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An Environmental and Economic Perspective on Integrated Weed Management in Iran

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Inputs, including herbicides, used in crop production may create negative environmental impacts. One solution to minimize these adverse effects is the adoption of integrated weed management (IWM) with the intention of reducing herbicide use. This study, conducted in 2010, estimates the willingness of farmers to pay for the adoption of more effective weed management methods. Results suggest that the willingness to pay (WTP) for IWM is greater than the WTP for other weed management methods, including chemical weed management and chemical and mechanical weed management. This study also identified a number of factors that influence the adoption of IWM on wheat farms in Iran using a multinomial logit model. Total annual income, area under irrigated wheat, wheat yield loss due to weeds, perennial nature of the weeds, and having awareness of weed resistance to herbicides had a positive effect on the adoption of IWM practices. However, having rain-fed (dryland) wheat cultivation and a larger number of plots on the farm had a negative influence on the choice of IWM.

Nomenclature: Wheat, *Triticum aestivum* L.

Key words: Economics, grower attitudes, integrated weed management, Iran, technology adoption, weed losses, wheat production, willingness to pay.

Insumos usados en producción de cultivos, incluyendo herbicidas, pueden generar impactos ambientales negativos. Una solución para minimizar estos efectos adversos es la adopción del manejo integrado de malezas (IWM) con la intención de reducir el uso de herbicidas. Este estudio, realizado en 2010, estima la disponibilidad de productores de pagar (WTP) por la adopción de métodos de manejo de malezas más efectivos. Los resultados sugieren que la WTP por IWM es mayor que la WTP por otros métodos de manejo de malezas, incluyendo el manejo químico de malezas y la combinación de manejo químico y mecánico. Este estudio también identificó un número de factores que influencian la adopción de IWM en fincas de trigo en Irán usando un modelo logit multinomial. El ingreso total, el área de trigo bajo riego, la pérdida de rendimiento del trigo debido a malezas, la naturaleza perenne de las malezas, y el conocer sobre la resistencia de las malezas a los herbicidas tuvo un efecto positivo sobre la adopción de prácticas de IWM. Sin embargo, el tener trigo dependiente de lluvia (sin riego) y un número grande de parcelas en la finca tuvo una influencia negativa sobre la escogencia de IWM.

In developing countries such as Iran, weeds result in a significant loss of revenue for farmers (FAO 2009). It is estimated that the annual damage to agricultural production caused by weeds is approximately 11% worldwide (Ahmadi 1998). Weed damage in developed countries is approximately 5 to 10%, while in developing countries damage is estimated at more than 25% (Hobbs and Bellinder 2004). In response to these losses, many producers have adopted herbicides for managing weeds such that an estimated 43% of total herbicide use occurs within agricultural production systems (Jayakumar 1995).

Wheat is an important crop for Iranian consumers. In 2006, a typical household consumed 486 kg of wheat in the form of bread. This consumption constituted 0.7% of the total expenditures for an Iranian household (Central Bank of Iran 2006). On the production side, wheat is also an important crop in Iran, particularly in the Khorasan Razavi province, which produces twice as much wheat as do the other provinces (Ghorbani et al. 2010).

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In Iran, yield losses due to weeds have been reported to account for 15.3 to 25% of the total wheat production (Ghorbani et al. 2010). Not only do weeds reduce the profitability of wheat production in the region, but they also increase production risks through higher variability in yields. As a result of economic losses, effective weed management in this region has become critical (Nemati 2009). Herbicides are commonly used by Iranian wheat farmers to manage weeds. Hatcher and Melander (2003) showed that to reduce crop losses, farmers apply herbicides too frequently, which results in water and soil pollution. Some herbicides can negatively affect water quality (Blackshaw et al. 2000; Funari et al. 1995; Ribaudo 1993), contribute to soil pollution, and may negatively impact wildlife such as insects, mammals, and birds (Luhdholm 1987; Mason et al. 1986; Murray 1985; Zimdahl 1999). Herbicide residues in food can also negatively affect human health (Blair and White 1985; Hoar et al. 1986; Sivayoganathan et al. 2000; Wigle et al. 1990).

Farmers are concerned about the risks of herbicides to human health and environmental quality (Beach and Carlson 1993; Florax et al. 2005; Higley and Wintersteen 1992; Mullen et al. 1997; Sydorovych and Marra 2008). The Fourth Development Program of Iran has selected the goal of sustainable agriculture, which calls for the decreased use of pesticides, including herbicides, while achieving effective management of pests. In light of the negative impacts of herbicide use, weed management tactics are needed that reduce crop damage while maintaining food security and increasing the sustainability of agricultural production (Ghorbani et al. 2010).

Alternatives to herbicide use do exist, including crop selection, biological and mechanical control, and IWM (Swanton and Murphy 1996). Although past weed management practices in Iran have not necessarily followed ecological and sustainable production principles, more recently the introduction of IWM techniques that reduce the use of herbicides has gained wide attention.

To achieve a higher level of sustainability, alternative methods of weed management are prescribed by weed specialists (Blackshaw et al. 2000). These methods may entail the adoption of a weed management program that minimizes the costs to producers (generating higher profits) and generates minimal damage to the environment and human safety; this approach is referred to as "ecological and sustainable weed management" (Florax et al. 2005; Kafle 2007; Owens et al. 1998; Shaner 1995). One practice within this approach is IWM.

IWM is defined as the use of several methods of weed management, including chemical, biological, and cultural practices. Cultural practices generally include the use of crop selection, cover crops, intercropping, manipulation of nitrogen fertility, planting patterns, tillage systems, and a critical period of weed management (Thill et al. 1991; Ullah et al. 2008). In fact, IWM is a combination of methods that has several benefits, including (1) reductions in environmental costs generated by chemical loading, (2) the provision of better and safer weed management (using methods that cause minimal damage to the environment and human safety and are based on local knowledge of controlling weeds), (3) reductions in the occurrence of herbicide-resistant weeds, and (4) efficient and sustainable management (Ghorbani et al. 2010; Nelson and Shearer 2009). Although IWM may not result in optimal control of weeds, it does prevent weed seed production and lowers seed germination over the long term (Bond and Grundy 2001; Chikoye et al. 2004).

To assess the role of IWM in wheat production in the Khorasan Razavi province of Iran, it is important to consider the major environmental and economic components of IWM and to identify factors that influence the adoption of IWM practices. The effectiveness of IWM on wheat farms for decreasing weed damage depends largely on the adoption level of IWM by farmers. A key question can thus be asked: What factors influence the selection of alternate methods of weed management by farmers in this region? Such knowledge could be used by public agencies to develop appropriate policies for adopting IWM and developing more sustainable agricultural production systems.

The primary objectives of this paper are twofold: (1) to estimate farmers' willingness (as measured by their WTP) to adopt IWM over other methods of weed management for the environmental benefits to society at large through reducing the negative effect of herbicides on the environment and (2) to determine the factors that influence decisions by farmers to adopt IWM on wheat farms in the Khorasan Razavi province of Iran.

Materials and Methods

Study Method for the Estimation of WTP and Scenarios. Given that weed management practices affect the environment and, consequently, environmental services (such as air quality, water quality, among others), losses to society from weed management cannot be estimated using economic losses alone. Hence, market prices alone cannot be used because many of the environmental services are not traded in the market place (a concept called non–market goods). Because of this, alternative methods of environmental valuation have been devised, the most common of which is the contingent valuation method (Ghorbani and Firozzare 2008; Venkatachalam 2003; Walsh et al. 1984). This method uses a hypothetical market for environmental goods and services and solicits individuals' WTP for a particular change in the level of such goods or services. The method involves either asking individuals their WTP through direct questions or approximating WTP through the cost of adaptive measures that would be undertaken in the absence of such goods and services (Ghorbani and Firozzare 2008).

In this study, the determination of farmers' WTP was accomplished using the approach suggested by Van Ravenswaay and Hoehn (1991) and Owens et al. (1998). This approach was selected because it minimizes hypothetical bias by simulating a market (buy-and-sell exercise) for a good that is similar to another good familiar to the respondent.

Respondents were provided with five different scenarios related to reducing the effects of herbicide use on four environmental outcomes: water pollution, threats to human health, soil pollution, and threats to beneficial insects (Table 1). Under each scenario, different levels of changes in these outcomes were selected. Farmers were asked to provide their WTP relative to scenario 1, which involved a 20% reduction in the water pollution level, a 10% reduction in the soil pollution level, a 50% reduction in the threat to human health, and a 50% reduction in the threat to beneficial insects. In other scenarios, the levels of reduction were gradually increased, reaching the maximum reduction level in scenario 5.

The same method was used to investigate the financial flexibility of farmers, in terms of WTP, to implement different weed management methods at the farm level. The study considered four weed management situations, with each situation resulting in a different percentage of weed reduction when implemented at different weed growth stages: germination, vegetative stage, and maturity. For example, in the first situation, farmers were asked to provide the WTP level for 100% weed reduction at the three stages of weed growth on their farms. These weed reduction percentages were decreased to 70, 50, and 30% under the other three situations.

Analysis of Producer Responses. Alternative methods used to determine factors that affect farmers' WTP include ordered models (eg. ,the ordered logit model) and nonordered models (e.g., the conditional logit model, nested logit model, multinomial logit [MNL] model, multinomial probit model, and logit model with heteroscedastic extreme value) (Ben-Akiva and Lerman 1985). In this study, the nonordered logit model in the MNL framework was applied to the farmer responses collected.

Logit models are used to compute the probability of selection between two or more choices. The most common model specification is the MNL model (Hausman and McFadden 1984). This type of model is appropriate when the responses fall into more than two categories and the assumption of a normal distribution is met. The MNL model provides a convenient closed form for the underlying choice probabilities without any requirement for multivariate integration. Therefore, choices that are characterized by many alternatives can be treated.

If the dependent variable can take more than two categorical values (for example, in this study, chemical weed management [CWM], chemical and mechanical weed management [CMWM], and weed management based on chemical, mechanical, and cultural practices [IWM], then qualitative choice models are called multinomial-choice models. In these models, alternatives of the dependent variables are denoted by numerical coding, such as 1, 2, and 3. In other words, MNL is used to test all combinations between J categories of the dependent variable. In these models, the utility of choice j is shown by U_j and defined in Equation 1:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \qquad [1]$$

where U_{ij} is a random utility of choice j to individual i, V_{ij} is a deterministic utility of choice j to individual i, and ε_{ij} is the unknown and random component of the utility of choices j.

Under the assumption that the error terms (ε_{ij}) follow a Gumble distribution, the choice probability function would be a logit model (Ben-Akiva and Lerman 1985). The general structure of the MNL model is shown in Equations 2 and 3, and Equation 3 presents the probability of adopting the ith weed management methods by wheat producers:

$$\Pr(Y_i = j) = \frac{Exp(X_i\beta_j)}{1 + \sum_{j=1}^{j} Exp(X_i\beta_j)} \qquad j = 1, \ldots, j$$

$$\Pr(Y_i = j) = \frac{Exp(X_i\beta_j)}{1 + \sum_{j=1}^{j} Exp(X_i\beta_j)} \qquad j = 1, \ldots, j \qquad [2]$$

$$\Pr(Y_i = 1) = \frac{1}{1 + \sum_{j=1}^{j} Exp(X_i\beta_j)} \qquad [3]$$

where Y_i is an observed dependent variable of the ith member, X_i is the vector of the independent variables of the ith member, and β_i represents the model parameters.

The estimation of the probabilities in the MNL is performed by selecting one category of dependent variable as a benchmark (comparison) category. In other words, the probability of selecting one category is evaluated against the selection of the benchmark category. The estimation of the coefficients of the model is achieved using the maximum likelihood (ML) method, which is based on maximizing the probability of the simultaneous occurrence of observations.

Table 1. Changes in weed management practices that decrease negative environmental effects of herbicides. Each scenario represents weed management inputs that will reduce different percentages of negative environmental effects.

Environmental parameters	Reduction of negative effects under five scenarios				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
			%		
Water pollution	20	30	50	70	80
Soil pollution	10	30	50	70	80
Threat to human health	50	70	80	80	90
Threat to beneficial insects	50	70	80	80	90

To investigate the existence of the effect of independent variables on the dependent variable, the likelihood ratio (LR) and Wald tests were used for each independent variable. For example, the LR test for X_i investigates whether two models (in which one model contains all independent variables and the other model—the reduced model—contains only an intercept term) are different. A statistic of the LR test (χ^2) is computed as shown in Equation 4:

$$\chi^2 = 2[LL(0) - LL(\beta)] \qquad [4]$$

where $LL(\beta)$ is the log likelihood of the final model, and $LL(0)$ is the log likelihood of the reduced model.

These log likelihoods are computed using Equations 5 and 6, respectively:

$$LL(\beta) = \sum_{j=1}^{n} \sum_{j=0}^{J} d_{ij} \ln \Pr ob(Y_i = j) \qquad [5]$$

$$LL(0) = \sum_{j=1}^{J} n_j \ln\left(\frac{n_j}{n}\right) \qquad [6]$$

where n is the sample size, n_j is the sample size in the jth category, and $d_{ij} = 1$ if the ith observation is placed in the ith category; $d_{ij} = 0$ otherwise.

A significant χ^2 statistic indicates a significant difference between the final and reduced models. It shows that the presence of X_i in the model is important. In other words, this variable has a significant effect on the dependent variable. Wald's test is similar to the LR test. It is computed using Equation 7, where the ratio of the independent variable coefficients to its standard error is squared:

$$W_j = \left(\frac{\beta_j}{SE_{\beta_i}}\right)^2 \qquad [7]$$

Wald's statistic, like the LR test, investigates the hypothesis that a given independent variable has a significant influence on the different dependent variables. Wald's statistic provides good results to large sample sizes, whereas LR is valid with higher confidence for small sample sizes. According to Greene (2003), the LR test is better than Wald's statistic using goodness of fit as the criterion. The criterion commonly used

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Table 2. Variables used in the integrated weed management multinomial logit model.

Variables	Descriptive	Measurement unit
Socio-demographic characteristics:		
Farmer's age (X_1)	Age—head of household	Year
Wheat cultivation experience (X_2)	Wheat cropping experience	Year
Farmer's education (X_3)	Education level—head of household	No education (base), low education level = 1, middle education level = 2, high education level = 3
Household employed (X_4)	Family members employed in agriculture	Number of persons
Economic characteristics:		
Total annual income (X_5)	Total annual income of farmer	Dollars (million rials)
Farm ownership (D_1)	All wheat cropping land owned?	Owned = 1, otherwise = 0
Farm characteristics:		
Irrigated wheat area (X_6)	Irrigated wheat area	Hectares
Rain-fed wheat area (X_7)	Rain-fed wheat area	Hectares
Wheat fields per farm (X_8)	Total number of wheat fields on farm	Number
Technical characteristics:		
Annual weeds present (D_2)	Binary variable	Yes = 1, otherwise = 0
Perennial weeds present (D_3)	Binary variable	Yes = 1, otherwise = 0
Weed management at germination stage (D_4)	Binary variable	Yes = 1, otherwise = 0
Weed management at vegetative stage[a] (D_5)	Binary variable	Yes = 1, otherwise = 0
Wheat yield loss due to weeds (% of total wheat production) (X_9)	Quantitative variable	Percentage
Awareness of weed resistance to herbicides (X_{10})	Binary variable	Yes = 1, otherwise = 0

[a] Weed management at the maturity level was used as a base.

to measure it is pseudo-R^2, which is computed in three alternative manners using Equations 8 through 10:

Pseudo-R^2 McFadden:

$$R^2_{MC} = 1 - \frac{LL(\beta)}{LL(0)} \quad [8]$$

Pseudo-R^2 Cox and Snell:

$$R^2_{CS} = 1 - \exp\left[-\frac{2}{n}[LL(\beta) - LL(0)]\right] \quad [9]$$

Pseudo-R^2 Nagelkerke:

$$R^2_N = \frac{R^2_{CS}}{R^2_{MAX}}, \quad where \quad R^2_{MAX} = 1 - \exp\left[2(n^{-1})LL(0)\right] \quad [10]$$

These pseudo-R^2s do not have interpretations similar to the commonly used R^2. A typical interpretation is that a higher level of pseudo-R^2 suggests a higher degree of goodness of fit of the data (Greene 2003). An alternative to the pseudo-R^2 is to estimate the percentage of correct predictions (classification accuracy) of the dependent variable (Pai and Saleh 2008).

In this study, three alternative methods of weed management were included: CWM, CMWM, and IWM. To investigate the factors influencing wheat farmers' selection of a given type of method over other methods, MNL models were estimated using SPSS 11.5 (Software and description in Nie et al. 1970). In this study, all comparisons were made with the benchmark category of the IWM method.

Factors that were hypothesized to affect a farmer's choice of a particular weed management method included ownership of the farm, the farmer's education level, the life cycle (annual or perennial) of most weeds on the farm, the choice of management tactic to be used at germination or vegetative growth stage of weeds, and an awareness of weed resistance to herbicides. Because growth stage of weeds is a qualitative variable consisting of three stages, the "maturity stage" was deleted to eliminate the possibility of perfect multicollinearity. All of these variables were discrete in nature and were complemented by nondiscrete variables, including the farmer's age, the farmer's years of experience in wheat production, the number of people in the household employed in agriculture, the total annual income, the area of irrigated and rain-fed wheat production, and the proportion of wheat yield lost due to weeds (Table 2).

Sample Size and Data Collection. To determine the appropriate sample size of farmers to use for analysis, a two-step procedure was followed. First a prestudy survey was completed using a structured questionnaire with 15 producers. Using the information on variability and required precision and the Cochran (1963) method, the total required sample size was determined to be 180 in 2010. Wheat producers of the Khorasan Razavi province were selected at random from five areas in the province, which were selected based on their importance in the province with regard to area under wheat production and yields (Table 3). Data were collected on weed management methods used and on various factors affecting the farmers' weed management choice, along with their socioeconomic profiles. Using the designed questionnaire, a face-to-face interview was used.

Of the 180 producers in the sample, over half (53.9%) used CWM, whereas CMWM was adopted by 27.2% of the respondents. The third method (IWM) was used by only 18.9% of the farmers (Table 4).

Sample Description. In terms of the respondents' characteristics, the average ages of wheat farmers in the CWM,

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Table 3. Distribution of sample respondents by regions in the Khorasan Razavi province.

Area of Khorasan Razavi province	Wheat-cultivated land	Percentage of Iran's total wheat-cultivated land	Wheat production	Percentage of Iran's total wheat production	Number of respondents
	ha	%	1000 X kg	%	
Mashhad	29,300	9.6	41,953	7.5	35
Sabzevar	35,700	11.7	46,897	10.2	38
Neishaboor	31,500	10.3	57,838	10.3	38
Torbat-e-Heidariyeh	19,900	6.5	44,996	8.0	25
Torbat-e-Jam	26,165	8.6	89,004	15.9	45
Total	305,526	46.8	560,704	15.0	180

CMWM, and IWM categories were 49.0, 47.6, and 43.3 yr, respectively (Table 5). This finding shows that the average age of farmers following CWM, the conventional approach using chemical, was relatively high. The average total yearly incomes of farmers using the three weed management approaches were US$4,243, $7,426, and $13,056 (52, 91, and 160 million rials yr^{-1}, respectively [converted using CoinMill.com (1970)]. This finding suggests that farmers with higher incomes use IWM more frequently in this region of wheat production.

Land ownership for wheat production also differed among the three weed management farmer groups. Farmers practicing CWM had a smaller proportion of area owned (87% of the total), whereas those practicing CMWM and IWM owned all their wheat hectares. Similarly, mean area under irrigated wheat production was highest for farmers practicing IWM (11.23 ha) relative to farmers using CMWM (6.1 ha) and CWM (2.96 ha).

The average farmer awareness index (binary variable: 1 = awareness, 0 = otherwise) about weed resistance to herbicides was similar for all three weed management groups (CWM = 0.7, CMWM = 0.76, and IWM = 0.8, respectively). One could conclude that farmers practicing IWM have a slightly higher awareness of this phenomenon than farmers in the other two weed management groups. The average percentage of wheat yield loss due to weeds was highest on farms using CWM (30.5%) compared with farms using CMWM (28.5%) and IWM (20.6%). From the responses, it was not clear whether farmers selected IWM because they knew of weeds' resistance to herbicides or simply decided to use it to delay resistance. However, these data confirm the perceived effectiveness of IWM approaches for weed management in wheat.

Results and Discussion

Valuation of Weed Management Methods. A comparison of weed management costs and wheat farmers' WTP for different scenarios under the three management methods (CWM, CMWM, and IWM) suggests a higher cost for those farmers using IWM than the other two control methods (Table 6). Weed management costs for CWM, CMWM, and IWM were US$11.88, $13.67, and $14.08 ha^{-1}, respectively (145,567, 167,551 and 172,500 rials ha^{-1}, respectively; [converted June 10, 2012, http://coinmill.com/IRR_USD.html]). Although the weed management costs for IWM are higher than the costs for the other two methods, IWM is a completely rational choice because the lower wheat crop losses due to weeds using this strategy compensates for the greater application costs.

Farmers were also asked for their preferences regarding the use of bio-herbicides that are considered by society to be safe alternatives to chemical herbicides. Their WTP for this type of weed management tactic was higher than their current cost of weed management (Table 6). Those using IWM were willing to pay US$26.26 ha^{-1} (equivalent to 321,770 rials ha^{-1}), which was greater than respondents using the other two methods (US$22.30 ha^{-1} or 273,270 rials ha^{-1} for CMWM and US$18.52 ha^{-1} or 226,910 rials ha^{-1} for CWM). The

Table 4. Number of farmer respondents using specific weed management methods in wheat in the Khorasan Razavi province, Iran.

Weed management method	Number respondents	Percentage of total
Chemical weed management	97	53.9
Chemical and mechanical weed management	49	27.2
Integrated weed management	34	18.9
Total	180	100

Table 5. Average value of variables used in the integrated weed management (IWM) multinomial logit model for wheat farmers in Khorasan Razavi province, Iran, using chemical weed management (CWM), chemical and mechanical weed management (CMWM), and IWM methods.

Variables	Average based on weed management method		
	CWM	CMWM	IWM
Socio-demographic characteristics:			
Farmer's age (yr)	49	47.6	43.3
Farmer's education	1.23	1.68	2.89
Wheat cultivation experience (yr)	22.7	23	22.5
Household employed (No. of persons)	6.1	6	5
Economic characteristics:			
Total annual income (US$)[a]	4243	7426	13,056
Farm ownership (owned = 1)	0.87	1	1
Farm characteristics:			
Irrigated wheat area (ha)	2.96	6.10	11.23
Rain-fed wheat area (ha)	2.67	2.36	2.94
Wheat fields per farm	3.60	3.18	3.29
Technical characteristics:			
Wheat yield loss due to weeds (expressed as % of total wheat production)	30.46	28.50	20.60
Awareness of weed resistance to herbicides (aware = 1)	0.70	0.75	0.80

[a] Converted from rials June 10, 2012.

Table 6. Comparison of willingness to pay (WTP) for weed management strategies in chemical (CWM), chemical and mechanical (CMWM), and integrated (IWM) weed management programs.

Weed strategies	WTP for weed strategies in each management program			WTP for "safe"[a] alternative over WTP for standard strategies in each management program		
	CWM	CMWM	IWM	CWM	CMWM	IWM
	US$ ha^{-1}					
Current costs	11.88	13.67	14.08	6.64	8.63	12.18
WTP for "safe" alternative	18.52	22.30	26.26	—	—	—
WTP in environmental scenarios[b]						
Scenario 1	11.85	13.52	14.04	7.05	8.78	12.22
Scenario 2	13.79	17.27	18.43	4.54	5.03	7.82
Scenario 3	16.61	21.05	23.59	1.91	12.49	2.66
Scenario 4	17.79	21.72	24.91	0.72	5.83	1.34
Scenario 5	18.08	23.65	30.41	0.43	−1.35	4.15
Average	15.58	19.44	22.28			
WTP for specific levels of weed control at each weed growth stage						
Germination/emergence						
100% control	13.86	15.75	15.82	4.66	6.54	10.44
70% weed control	10.54	11.77	11.57	7.97	10.53	14.69
50% weed control	7.39	8.13	8.04	11.13	14.17	18.22
30% weed control	0.29	0.50	0.46	18.23	21.80	25.80
Average	8.02	9.04	8.97			
Vegetative growth						
100% weed management	16.99	20.15	20.83	1.52	2.15	5.42
70% weed management	13.02	15.29	15.74	5.50	7.01	10.51
50% weed management	9.79	10.93	11.16	8.72	11.37	15.10
30% weed management	0.39	0.77	0.72	18.13	21.53	25.54
Average	10.04	11.78	12.11			
Maturity						
100% weed management	18.06	23.92	27.67	0.45	−1.62	−0.03
70% weed management	15.30	18.24	20.33	3.21	4.06	5.93
50% weed management	11.58	13.09	14.40	6.93	9.21	11.86
30% weed management	0.50	0.97	0.86	18.02	21.33	25.35
Average	11.36	14.05	15.82			

[a] "Safe" weed management methods were defined as those that cause minimal damage to the environment and human safety and are based on local knowledge of controlling weeds.

[b] Scenarios 1 through 5 represent weed management inputs that will reduce different percentages of negative effects from herbicides on water pollution, soil pollution, threat to human health, and threat to beneficial insects (see Table 1 for percentages).

higher WTP of farmers using IWM can be rationalized on the following grounds: (1) farmers using IWM have an increased negative perception of the environmental impact of herbicide use, (2) these farmers have greater financial means than other farmers in the province, and (3) farmers using IWM have observed its efficacy in reducing wheat yield losses due to weeds. However, this is left for future investigation in this area.

The average WTP of farmers, following the three methods of weed management under the five selected environmental scenarios as detailed in Table 1 suggests that the WTP of farmers using IWM was higher for all five scenarios relative to the WTP of farmers using the other two methods of weed control (Table 6). For example, for a higher level of protection of the environment (scenario 5), average WTP of farmers selecting IWM was US$30.41 ha^{-1}, as against US$18.08 ha^{-1} for those selecting CWM.

In addition to estimating average WTP, further analysis of a farmer's WTP for weed management during the three different stages of weed growth was also performed. The WTP of farmers was positive for various levels of weed damage management and for various stages of weed growth (Table 6). On average, the WTP of farmers under each of these situations was higher for those using IWM than for the farmers using the other two methods of management, especially those using CWM.

The last three columns of Table 6 present the marginal values for costs and WTP relative to the use of safe weed management methods for various scenarios and weed growth stages. This method was defined as the one that causes minimal damage to the environment and human safety and is based on local knowledge of controlling weeds. Overall, results suggest that wheat farmers in the Khorasan Razavi province have a higher WTP for perceived safer weed management tactics than the other three methods of weed management. Similarly, the average WTP at different levels of weed management at the germination, vegetative, and maturity stages of weed growth was higher when safer bio-herbicides for weed management were an option. The only exception was for scenario 5, where a negative marginal WTP was noted, but the average WTP was positive. This is due to weed management costs increasing when changing from a CWM strategy to an IWM strategy. Furthermore, in scenario 5, pollution and other hazards were minimized resulting in a higher WTP for IWM relative to the perceived safer management option of bio-herbicides. These results suggest

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Table 7. Factors influencing the adoption of integrated weed management.

Variables	−2 Log likelihood of reduced model	$\chi2$
Constant[a]	95.165	8.301 ns[b]
Farmer's age	−55.048	1.128 ns
Wheat cultivation experience	53.929	0.009 ns
Household employed	54.522	0.602 ns
Total annual income	163.535	109.615*
Irrigated wheat area	81.274	27.354*
Rain-fed wheat area	−75.236	21.316ns
Wheat fields per farm	−72.807	18.886***
Weed damage percentage	55.296	1.376**
Farmer's level	67.634	13.714 ns
Farm ownership	53.920	0
Annual weeds present	97.434	45.513 ns
Perennial weeds present	54.284	0.364**
Weed management at the germination stage	−53.920	0
Weed management in the vegetative stage	53.920	0
Awareness of weed resistance to herbicides	55.899	1.979**
Information of overall estimation of reduced model		
−2 Log likelihood	53.920	
χ^2	306.859*	
(Pseudo R^2) goodness of fit criteria		
Cox and Snell	0.81	
Nagelkerke	0.94	
McFadden	0.85	

[a] Implies the level of probability of adoption of the said technology when all factors take a value of zero. However, this is a statistical interpretation, and has little meaning in economic or practical areas.

[b] Abbreviation: ns, nonsignificant.

* Significantly different from zero at type 1 error at 1%.

** Significantly different from zero at type 1 error at 5%.

*** Significantly different from zero at type 1 error at 10%.

that farmers in the province are willing to adopt safe weed management methods in their wheat production systems.

Factors Influencing the Selection of IWM. The statistical validity of the MNL model was tested using the ML test. Comparison of the estimated model against the one with only an intercept (that is, no explanatory variables) resulted in a significant value of ML (reduced test value = 53.92) (Table 7). In other words, based on this evidence, the hypothesis that the selected independent variables play roles in the selection of a particular weed management method was accepted. To investigate the goodness of fit of the MNL and the relationship between the independent variables and the dependent variable, the criterion of pseudo-R^2 was applied. These results suggest that the MNL model has a high goodness of fit to the actual observed behaviors of farmers.

Based on the χ^2 test and other tests of significance, factors that had a positive and highly significant ($P < 0.01$) influence on the selection of IWM include the total annual income of farmers (a measure of size of farm) and the area of wheat under irrigation. In other words, because of their high financial ability, large farms are likely to use IWM more frequently than other farmers, especially relative to those with smaller farms (Table 7). However, the size of farm was not related directly to number of parcels of land under wheat cultivation on a farm; this variable indicated the state of fragmentation of the farm. In fact, IWM methods are generally more expensive than CWM and CMWM and thus carry a higher financial risk. Therefore, the early adopters of

Table 8. Forecasting ability of the model for weed management practices.

Actual weed management farms	No. of predicted weed management farms: Group 1[a]	Group 2	Group 3	Percentage of correct predictions
Group 1	97	0	0	100.0
Group 2	0	42	7	85.7
Group 3	0	7	27	79.4
Overall percentage of correct predictions	53.9	27.2	18.9	92.2

[a] Group 1 = chemical management,group 2 = chemical and mechanical weed management,group 3 = integrated weed management.

these methods are typically large-scale farmers (those with average farm income of more than $13,056 annually). The amount of irrigated wheat area on the farm contributes to a higher farm income and therefore has a similar effect on the choice of IWM. Factors such as the extent of weed damage to the wheat crop, the perennial (as opposed to annual) nature of the weeds, and a farmer's awareness of weed resistance to herbicides also had positive influences on their adoption IWM.

In addition to these variables, the number of fields under wheat on a given farm (a state of fragmentation of the farm unit) had a negative effect on the choice of IWM. The degree of fragmentation is typically related to size of farm; generally speaking smaller farms have more parcels of land. Due to this high degree of fragmentation, farmers with smaller farms have a lower willingness to implement IWM. This may in part be due to increased cost of implementing IWM relative to other methods. The presence of perennial weeds on wheat farms had a positive effect on the use of IWM because perennial weeds are more difficult to manage than annual weeds, and IWM is a more effective method of weed management under these circumstances (Ghorbani et al. 2010). Farmers also reported that the effectiveness of many herbicides to manage perennial weeds is low, and adopting IWM can increase the effectiveness and efficiency of controlling perennial weeds. Therefore, they have a higher willingness to apply IWM at the farm level.

The level of damage caused by weeds (losses in yield of wheat induced by weeds) had a positive effect on the adoption of IWM. This finding is perhaps explained by the increased efficiency of this method for weed control.

Ownership of a farm also had a positive impact on the selection of IWM. Those farmers who own all of their land are more likely to adopt IWM relative to other methods. Farmers who rent a portion of their land are more likely to adopt either CWM or CMWM likely because IWM requires a long-term planning perspective, which may not be possible for farmers who rent land.

In addition to the econometric evaluation of the estimated model, a true test of its validity is its power to make accurate predictions. The predictive ability of the model was found to be very high, as 92.2% of the actual observations were predicted accurately (Table 9). Overall, the MNL model predicted 92.2% of the variation of sample individuals in the various weed management classes.

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Table 9. Results of the logit model between chemical weed management (CWM) and integrated weed management (IWM) groups.

Variables	Coefficient	Standard error	Wald test	Exp(B)	95% confidence interval of Exp(B)	
					Low bound	High bound
Farmer's age	1.66	120.91	1.88 ns[a]	1.26	0.57	2.76
Wheat cultivation experience	−0.52	0.29	3.21 ns	0.94	0.53	1.66
Household employed	−0.88	0.87	1.02 ns	0.41	0.07	2.3
Total annual income	−0.28	0.32	0.76**	0.56	0.41	1.48
Irrigated wheat area	−3.02	1.62	3.47***	0.62	0.85	497.04
Rain-fed wheat area	1.52	0.91	2.79***	4.6	0.76	27.9
Wheat fields per farm	1.76	0.96	3.36***	2.17	0.026	1.132
Extent of weed damage to crop yield (%)	−0.15	0.11	1.86***	0.85	0.68	1.07
Farmer's education, 1[b]	7.57	4.48	2.85 ns	2.09	7×10^{-5}	3.35
Farmer's education, 2	0[c]	—	—	—	—	—
Farms ownership, 1[b]	−1.08	0.58	3.47 ns	0.86	2.96	2.96
Farms ownership, 2[d]	0[c]	—	—	—	—	—
Annual characteristics of weeds, 1[b]	1.89	2.32	0.66 ns	1.27	0.013	1.043
Annual characteristics of weeds, 2	0[c]	—	—	—	—	—
Perennial characteristics of weeds, 1[b]	−0.72	3.73	0.038***	0.48	0	728.01
Perennial characteristics of weeds, 2	0[c]	—	—	—	—	—
Weed management in the germination stage, 1[b]	0.57	2.08	0.076 ns	1.77	0.03	106.36
Weed management in the germination stage, 2	0[c]	—	—	—	—	—
Weed management in the vegetative stage, 1[b]	−0.83	2.23	0.138 ns	0.34	0.19	75.24
Weed management in the vegetative stage, 2	0[c]	—	—	—	—	—
Awareness of weed resistance to herbicides, 1[b]	−1.35	1.77	0.58***	0.86	0.12	124.71
Awareness of weed resistance to herbicides, 2	0[b]	—	—	—	—	—

[a] Abbreviation: ns, nonsignificant.
[b] Comparison categories. CWM = 1, IWM = 2.
[c] This parameter is set to zero because it is redundant.
[d] This variable takes two values: 1 where all cultivated wheat land is owned, and 2 when it is under other types of ownership.
* Significantly different from zero at type 1 error at 1%.
** Significantly different from zero at type 1 error at 5%.
*** Significantly different from zero at type 1 error at 10%.

Factors Affecting the Choice of CWM vs. IWM. The choice of a weed management method to use (CWM vs. IWM) is dichotomous. This type of formulation is tested using an MNL model. The estimated coefficients show the reasons why farmers in the Khorasan Razavi province select CWM and not the benchmark category (IWM) (Table 10). Factors that discourage producers from adopting CWM (and thus encourage them to adopt IWM) include the following: number of years of experience in wheat production, number of household members who are employed on the farm, total annual income, irrigated wheat area, level of wheat yield losses due to weeds, the presence of perennial weeds, weed management when plants are in the vegetative stage, and an awareness of weed resistance to herbicides. By contrast, the factors that induced farmers to adopt CWM include the farmer's age, the area of rain-fed wheat, the number of parcels of farmland, the farmer's education level, the annual nature of weeds, and weed management at early weed growth stages (germination/emergence). The numerical value of Exp(B) of the total annual income of farmers shows that an increase of 1 rial (1 rial is equivalent to one-thousandth of a U.S. dollar) would decrease the probability of adopting CWM by 0.56 (relative to IWM), if other variables do not change. In other words, by increasing the average total annual income of wheat farmers by 1%, the probability of adopting CWM will be reduced by 44% (with a corresponding increase in the adoption of IWM) when all other factors are held constant. This increase is a result of higher financial ability of farmers with larger farms who can afford higher costs of IWM. In fact, annual income is an important factor governing the choice of IWM, although other social and farm variables also affect this decision. Since irrigation is also positively related to size of farm, having irrigation also improves the probability of a farmer adopting IWM.

The estimated values of Exp(B) for farmer age show that if there is an increase of 1 yr in the average age, then the probability of using CWM vs. IWM will be 1.26 units higher IWM provided that other factors do not change. Because the adoption of IWM requires greater physical and financial ability, its adoption would decrease as a farmer's age increases. In addition, the low preference for taking high risks by older farmers coupled with the ease of use of CWM would contribute to a decision to choose this method over IWM. The coefficient of Exp(B) for the number of household members who are employed in agriculture showed that by increasing the number by one person, the probability of using CWM would decrease by 0.41 units relative to the other methods, with all other factors held constant. This result is logical because farmers with more family members use more labor-intensive weed management methods, such as CMWM and IWM. The coefficient of Exp(B) of the awareness of weed resistance to herbicides shows that an increase of 1% in the awareness of weed resistance to herbicides would reduce the probability of selecting CWM by 14%. As weed resistance to herbicides increases, CWM becomes less effective, and alternative methods such as IWM are preferred.

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Table 10. Results of logit model between chemical and mechanical weed management (CMWM) and integrated weed management (IWM) groups.

Variables	Coefficient	Standard error	Wald test	Exp(B)	95% confidence interval of Exp(B)	
					Low bound	High bound
Constant	7.593	4.433	2.921***	—	—	—
Farmer's age	0.003	0.071	0.002 ns[a]	1.003	0.873	1.152
Wheat cultivation experience	0.029	0.068	0.182 ns	1.029	0.900	1.177
Household employed	0.198	0.232	0.728 ns	0.820	0.521	1.291
Total annual income	−2.092	1.571	1.773*	0.077	0.004	1.690
Area of wheat irrigated	−0.115	0.078	2.173***	0.78	0.963	1.306
Area of rain-fed wheat	0.049	0.123	0.159ns	1.051	0.826	1.337
Wheat fields per farm	0.394	0.231	2.91***0	0.675	0.429	1.060
Weed damage percentage	0.023	0.031	0.550***	0.977	0.920	1.038
Farmer's education, 1 [b]	0.302	0.758	0.158 ns	0.740	0.167	3.268
Farmer's education, 2	0[c]	—	—	—	—	—
Farm ownership, 1 [b]	1.376	0.736	3.498 ns	0.253	0.059	1.068
Farm ownership, 2	0[c]	—	—	—	—	—
Annual characteristics of weeds, 1 [b]	0.198	0.101	3.843 ns	1.219	0.999	1.486
Annual characteristics of weeds, 2	0[c]	—	—	—	—	—
Perennial characteristics of weeds, 1 [b]	−0.684	0.758	0.814**	0.891	0.449	8.748
Perennial characteristics of weeds, 2	0[c]	—	—	—	—	—
Weed management at the germination stage, 1][b]	0.398	0.893	0.198 ns	0.672	0.117	3.870
Weed management at the germination stage, 2	0[c]	—	—	—	—	—
Weed management at the vegetative stage, 1[b]	0.738	1.221	0.365 ns	2.091	0.191	22.910
Weed management at the vegetative stage, 2	0[c]	—	—	—	—	—
Awareness of weed resistance to herbicides, 1[b]	−1.006	0.749	1.804***		0.630	11.871
Awareness of weed resistance to herbicides, 2	0[c]	—	—	—	—	—

[a] Abbreviation: ns, nonsignificant.

[b] Comparison categories. CWM = 1, IWM = 2.

[c] This parameter is set to zero because it is redundant.

* Significantly different from zero at type 1 error at 1%.

** Significantly different from zero at type 1 error at 5%.

*** Significantly different from zero at type 1 error at 10%.

Factors Affecting the Choice of CMWM vs. IWM. The second model was estimated to explain the preference of farmers for selecting CMWM over IWM. The methodology of evaluation for this model was similar to that for the first model. The variables that were found to negatively affect the choice of CMWM were as follows: total annual income, irrigated wheat area, perennial nature of weeds, and an awareness of weed resistance to herbicides (Table 10). At the same time, the choice of this method was positively affected by two factors: the number of land parcels on the farm and the level of wheat yield losses due to weeds (measured as a percentage), which at the same time reduced the preference for IWM.

These results also suggest that if the density of perennial weeds increases by 1%, the probability of selecting CMWM will be 11% lower than that of IWM, provided that other factors do not change, because the latter method is better suited to the management of perennial weeds on farms. The coefficient for the irrigated wheat area suggests that an increase of 1 ha would reduce the probability of selecting CMWM over IWM by 22%, if other variables remain constant. Farmers with larger areas under irrigation also have a higher financial ability and are therefore more inclined to adopt IWM.

Examination of the coefficient of Exp(B) for the number of years of experience with wheat cropping systems shows that an increase of 1 yr of experience would decrease the chance of selecting CMWM by 2.9%, when all other factors are held constant. In fact, more experienced farmers typically have a higher awareness of the losses caused by weeds and are more likely to employ more diverse methods of weed management, such as IWM.

Farmers in the Khorasan Razavi province of Iran have a high willingness to pay for the use of safer herbicides. Thus, the development of such herbicides, as well as the development of stricter regulations on the use of chemicals, should lead to more sustainable agricultural production systems. The environmental benefits from such policies would be high.

Several factors play an important role in a farmer's decision as to which weed management method to use. Farmers are aware of both the negative environmental impact caused by herbicides and of the development of herbicide resistance. Effective on-field and farmer-led demonstration studies and educational programs would be major steps toward persuading farmers to adopt more sustainable weed management strategies such as IWM.

Findings also showed that farmers with higher incomes (related to larger farms) adopted IWM tactics more frequently than smaller farms. In fact, the financial ability of the farm (which is governed in part by the size of the farm and the area under irrigation) is a major determinant of the adoption of IWM. Therefore, the target groups selected for the adoption of IWM should be large-scale farmers because they have the required willingness to adopt IWM. For other (particularly smaller) farmers, a subsidy program or other form of incentive could be developed. However, an analysis of the desirability and cost effectiveness of these programs for these farmers is warranted as a further study.

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