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Analysing the importance of glyphosate as part of agricultural strategies – a discrete choice experiment

Michael Danne

Oliver Mußhoff

Michael Schulte

Department für Agrarökonomie und

Rurale Entwicklung

Universität Göttingen

D 37073 Göttingen

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Abstract

The use of glyphosate plays an important role in farmers' strategic decisions for reducing weed pressure and yield losses. In this paper, the use of glyphosate is analysed as part of a complete agronomic strategy in which the farmer has to choose between the use of a combination of mechanical and chemical weed control. A special aim was to analyse the trade-off in the farmers' preferences between a cultivation strategy with or without glyphosate. The empirical analysis is based on a discrete choice experiment with 328 German farmers. It was found that after the harvest of rapeseed, farmers have no clear preference for the use of glyphosate in a mulch seeding strategy. However, the preference for glyphosate use is affected by the weed pressure and the presence of specific weeds. While the farmers' risk attitude has no influence on the decision to use glyphosate, we observed an increasing preference for its use on larger farms. Furthermore, our results reveal that farmers prefer mechanical weed control in pre-sowing instead of the use of selective herbicides in pre- or post-emergence. This preference increases if weed resistance is an issue on the farm. Potential yield impacts caused by glyphosate use show that yield losses have a higher impact on the farmers' decision than yield gains. We conclude that farmers prefer the use of glyphosate to other alternatives as it is an important part of their agronomic strategy to prevent weed infestation and save work and labour costs, especially on large farms.

Keywords: Glyphosate; mulch seeding; rapeseed; agronomic strategy; discrete choice experiment; farmers' preference

1 Introduction

Weed control is an important issue in agricultural systems. Weeds can be effectively reduced with the use of herbicides (Gruber *et al.*, 2004), intensive tillage or a combination of tillage and the application of glyphosate (Duke and Powles, 2008; Steinmann *et al.*, 2012). The use of herbicides is a popular strategy in weed management (Chikowo *et al.*, 2009) because they are very effective in the reduction of weed pressure and therefore yield losses and have encouraged the simplification of plant production and the adoption of reduced tillage systems (Buhler *et al.*, 2000). Reduced tillage is associated with fuel and labour savings, as several tillage actions may be substituted by a small number of herbicide applications (Gianessi, 2013). The nonselective, systematic herbicide glyphosate (N-(phosphonomethyl)glycine) is the main herbicide used worldwide (Woodburn, 2000; Duke and Powles, 2008; Steinmann *et al.*, 2012; Benbrook, 2016). The worldwide importance of glyphosate is mainly attributable to the cultivation of genetically-modified crops to which glyphosate resistance has been introduced. However, the cultivation of genetically-modified crops has not become a common agricultural practice in Europe so far and, therefore, the application of glyphosate with herbicide-resistant crops is not of interest (Wiese *et al.*, 2017). Nevertheless, glyphosate plays a pivotal role in the control of a wide range of weed species in European farming systems (Corbett *et al.*, 2004; Cook *et al.*, 2010; Steinmann *et al.*, 2012; Garvert *et al.*, 2013). Looking back, the use of glyphosate increased from 1999 to 2010 by 20% per year (Steinmann *et al.*, 2012). In Germany, for example, glyphosate is the most frequently used herbicide, with annual sales of approximately 5,000 tons and application to 39% of arable land (Steinmann *et al.*, 2012). In the UK, one third of the arable land was treated with glyphosate in 2014 (Garthwaite *et al.*, 2015). Underpinning the importance of glyphosate, Garvert *et al.* (2013) calculated that a ban on glyphosate would result in an annual welfare loss of 1.4 billion € in the European Union.

Specific uses for glyphosate applications include reduction of weed infestations in reduced tillage systems (Wiese *et al.*, 2017), off-season treatments to control a broad spectrum of annual and perennial weeds (Powles *et al.*, 1998), and the substitution of mechanical weed control for example in the removal of cover and volunteer crops (Steinmann *et al.*, 2012). Besides its versatility and efficiency, glyphosate became popular due to declining product prices for glyphosate and increasing diesel prices (Nail *et al.*, 2007).

However, in 2016, the authorization for glyphosate in the EU was only extended by 18 months, and therefore would have expired at the end of 2017. The initial plan of the European Commission to extend glyphosate approval for 10 years was not supported, so a compromise of a five-year extension was reached. The main opposition to glyphosate stems from its potential negative impacts for human health, ecosystems and agricultural system stability, which have led to a public and scientific debate about the use of glyphosate (Kurstjens, 2007).

The question arises of how important the use of glyphosate is in comparison to mechanical weed control techniques and which impacts a ban of glyphosate would have for European farmers. Wynn *et al.* (2014) calculated the glyphosate use in Germany, the UK and France and figured out that a prohibition of glyphosate may result in considerable economic losses for farmers. A further study of Wiese *et al.* (2017) used a dataset of German arable farmers to evaluate glyphosate use in different agricultural situations, i.e., at pre-sowing, pre-harvest and post-harvest, with a focus on winter wheat, oilseed rape, sugar beet and maize. In their analysis, a zero-and-one inflated beta regression was applied which measured the probability of glyphosate use depending on different predictor variables, such as farm size or working time. However, this study is an ex-post analysis that focusses on the glyphosate consumption as a dependent variable instead of analysing glyphosate use as part of a complete strategy in which the farmer has to decide between a combination of mechanical and chemical weed control. More specifically, the trade-off in the farmers' preferences between a cultivation strategy with or without glyphosate was not evaluated until now.

Against this background, the research challenge of this paper is to analyse the trade-off in farmers' preferences between mulch seeding with or without glyphosate and to identify drivers of glyphosate use from the farmers' perspective. More specifically, we analyse the impact of agricultural, farmer-related and individual farm factors on the use of glyphosate. The novelty of this paper is, especially in contrast to Wiese *et al.* (2017), the estimation of farmers' preferences for glyphosate as a multi-dimensional ex-ante decision instead of focusing ex-post on the hectares treated with glyphosate as a one-dimensional dependent variable.

The study seeks to understand farmers' perceptions by conducting a discrete choice experiment (**DCE**) with farmers in Germany. The DCE is a suitable tool to confront farmers with a real agronomic decision in which they have to balance and decide between different components of a cultivation strategy. Therefore, this innovative method allows measurement of the trade-offs in the farmers' preferences for different cultivation strategies. German agriculture is characterized by diverse farm size, geography, climate and agricultural conditions and is therefore suitable to represent farming systems throughout Central Europe. Farmers' preferences are analysed using a generalized multinomial logit model (**GMNL**), which allows scale heterogeneity to be considered between individuals. With this approach, we are building on previous studies in the fields of agricultural and environmental research estimating farmers' preferences, e.g., for Greening attributes or farmers' willingness to produce GM-free milk (Christensen *et al.*, 2011; Schulz *et al.*, 2014; Schreiner and Latacz-Lohmann, 2015). The research presented in this study contributes to the debate about a glyphosate ban by shedding light on how farmers evaluate glyphosate as part of an agronomic strategy, especially in comparison to strategies without the use of glyphosate. Individual farmer and farm characteristics are thereby used to give detailed insights into farmers' choice of strategy.

The paper is structured as follows. It begins with the derivation of hypotheses. The following section documents the data and the design of the DCE. After that, the econometric model is specified. Subsequently, the results of the DCE are presented and discussed. Finally, we give a conclusion of our analysis.

2 Derivation of Hypotheses

We focus on the cultivation of winter wheat after harvesting rapeseed for the following reasons. In Germany, more than 70 % of the rapeseed land is treated post-harvest with glyphosate to prevent negative effects of volunteers (Wiese *et al.*, 2017). The removal of volunteer rapeseed after harvest is an important task to prevent weed problems and therefore yield losses in subsequent crops (Pekrun *et al.*, 1998; Lutman *et al.*, 2005). Rapeseed is very vulnerable to secondary seed dormancy, so a flat tillage in combination with a glyphosate application is more effective than repeated deep tillage (Pekrun *et al.*, 1998). Moreover, the deep roots of rapeseed leave optimal conditions for reduced tillage before seeding the following crop. However, this management option leads to higher glyphosate applications (Wiese *et al.*, 2017). In this context, we expect that after rapeseed, farmers prefer mulch seeding with the use of glyphosate over mulch seeding without glyphosate (Hypothesis 1a).

Under optimum conditions, tillage achieves a similar result to that of herbicides with glyphosate as their active ingredient (Chandler *et al.*, 1994; Tørresen *et al.*, 2003); however, black grass (*Alopecurus myosuroides*) is more effectively controlled with glyphosate than with mechanical soil cultivation (Lutman *et al.*, 2013). Based on the aforementioned findings, we can expect that the decision to use glyphosate is affected by the weed pressure and the presence of specific weeds (Hypothesis 1b).

Risk is an important factor in a farmer's decisions about the use of herbicides for weed control (Horowitz and Lichtenberg, 1994). Horowitz and Lichtenberg (1994) list the degree of pest infestation, weather, prices and biological factors as potential sources of risk for an efficient application of pesticides that does not inflict damages. Carlson (1979) defines the application of pesticides as a risk-reducing action of farmers, meaning risk-averse farmers would apply more of them than risk-neutral farmers. This is supported by Liu and Huang (2013), who studied the risk preferences and pesticide use of Chinese cotton farmers. However, the risk-increasing character of pesticides was demonstrated by Pannell (1991), who found that pesticide use is associated with greater income variability. In this case, a risk-averse farmer would reduce pesticide application. A further argumentation for the risk-increasing character of pesticides is linked to the negative externalities of pesticide use. These externalities include herbicide resistance and damage to soil, groundwater, flora, fauna and human health (Wilson and Tisdell, 2001; Brethour, 2002; Chalak *et al.*, 2008). It might be assumed that risk-averse farmers would reduce their herbicide use to reduce external costs. However, Wilson and Tisdell (2001) show that, despite increasing external costs, farmers apply pesticides in high dosages. Therefore, we expect that the farmers' risk attitude influences their preference for glyphosate use (Hypothesis 1c).

In previous studies, the impact of farm size on the adoption of specific production practices was identified. For example, Fernandez-Cornejo *et al.* (2001) found a positive relationship between farm size and the adoption of GM herbicide-tolerant crops. Lambert *et al.* (2007) identified farm size as a driver of the decision to adopt agri-environmental practices. Furthermore, Sharma *et al.* (2011) found a positive correlation between farm size and the adoption of integrated pest management strategies. Young (2006) states that with increasing farm size and therefore a higher demand for skilled labour, the farmers' dependence upon herbicides for timely weed control increases. In addition, Johnson and Gibson (2006) found that large-scale farmers in India have other herbicide-application habits than small-scale farmers. Arguing that increasing farm size results in higher whole-farm risk, Osteen *et al.* (1988) and Osteen and Fernandez-Cornejo (2013) state that the pesticide use is higher on large farms to reduce profit losses due to weed pressure. Wiese *et al.* (2017) found in their analysis of glyphosate use by German farmers that large farms are more likely to use glyphosate instead of waving its use (Wiese *et al.*, 2017). Based on the aforementioned findings, it can be expected that the preference for glyphosate use increases with an increasing farm size (Hypothesis 1d). Altogether, we formulate the following hypotheses:

Hypothesis 1

a) After the cultivation of rapeseed, farmers prefer mulch seeding with the use of glyphosate over mulch seeding without glyphosate.
b) The farmers' decision to use glyphosate is affected by the weed pressure and the presence of specific weeds.
c) The risk attitude of farmers influences their preference for the use of glyphosate.
d) The preference for glyphosate use increases with increasing farm acreage.

The decision to use glyphosate is part of a strategy that combines mechanical weed control with the use of herbicides. Therefore, in addition to the decision about the use of glyphosate, farmers have to consider which proportion of mechanical weed control to use in pre-sowing versus the use of a selective herbicide in pre- or post-emergence which is designed to target a specific type of weed, thus avoiding harm to the crop (Moss, 2017).

Tillage is an essential part of the farming process as it is important for both seedbed preparation and mechanical weed control (Givens *et al.*, 2009). Weed populations are influenced by the combined effects of mechanical destruction and changes in the vertical distribution of weed seeds in the soil. Furthermore, tillage has an impact on the soil conditions which influence weed dormancy, germination and growth (Peigné *et al.*, 2007). Mechanical weed control at regular intervals can lower the germination rate of weeds in general and suppress the growth of spreading perennial weeds in particular. The extent of tillage efficacy depends on the weather conditions afterwards as well as the type of weed (Chandler *et al.*, 1994; Tørresen *et al.*, 2003). However, an increased share of mechanical weed control may be constrained by high demand and costs of labour and machinery (Llewellyn *et al.*, 2012; Böcker *et al.*, 2018) whereby this effect decreases if weed pressure after sowing is high. In this case, the use of more expensive selective herbicides is favourable (Böcker *et al.*, 2018). Buhler (1995) observed a trend in the last years of farms transitioning from intensive to reduced tillage systems. This change has slowed due to a reduction in the efficacy of the herbicides upon which reduced tillage systems rely heavily. The reduced efficacy is often related to the frequent use of herbicides as the preferred weed management tool (Llewellyn *et al.*, 2004), thus causing herbicide resistance in weeds to develop (Llewellyn *et al.*, 2002). Although farmers are able to choose herbicides from a broad range of products, only 15-20 modes of action are available in present herbicides (Cobb and Kirkwood, 2000). Additionally, the admission of new herbicides to the market with innovative modes of action has decelerated considerably (Rüegg *et al.*, 2007). Against this background, increasing resistance against selective herbicides presents one of the major issues in arable farming in Europe (Heap, 1997; Heap, 2014). Moreover, farmers are confronted with public concerns about the use of herbicides because of potentially negative impacts for human health, ecosystems and agricultural system stability (Kurstjens, 2007). As a consequence, measures aiming at a reduction of herbicide use, e.g. banning specific herbicides or introducing taxes on herbicides (Böcker and Finger, 2017), are discussed. Based on the aforementioned findings, we expect that mechanical weed control in pre-sowing is preferred over the use of selective herbicides in pre- or post-emergence (Hypothesis 2a). Furthermore, it is expected that the presence of resistance towards selective herbicides increases the preference of farmers for mechanical weed control (Hypothesis 2b).

In the case of resistance towards selective herbicides, the application of glyphosate is one of a number of alternative management options. Particularly in areas with high proportions of winter cereals in the crop rotation, a pre-sowing treatment with glyphosate provides an effective defence against black grass and silky bent grass (*Apera spica-venti*), which often show resistance to other common classes of herbicide active ingredients (ACCase- and ALS inhibitors) (Moss, 2017). However, spraying glyphosate for several years may also cause weed communities to evolve, which has resulted in the need for higher dosages to control weeds (Shaner, 2000) and resistance towards glyphosate in biotypes of five weed species in Europe (Heap, 2018). However, we expect that if resistance towards selective herbicides is present, farmers have a higher preference for the use of the non-selective herbicide glyphosate (Hypothesis 2c).

Hypothesis 2

a) After rapeseed, farmers prefer mechanical weed control in pre-sowing versus the use of selective herbicides in pre- or post-emergence.
b) The presence of herbicide resistance towards selective herbicides increases the farmers' preferences for mechanical weed control instead of the use of selective herbicides.
c) The presence of herbicide resistance towards selective herbicides increases the farmers' preferences for the use of glyphosate.

The use of plant protection products has a positive effect on the yield of field crops (Oerke and Dehne, 2004). Concerning the use of glyphosate, existing studies show different results. While Cook *et al.* (2010) and Garvert *et al.* (2013) expect appreciable yield depression without glyphosate, Schulte *et al.* (2016) found that the main advantage of glyphosate is the reduction of costs for machinery and labour. Yield reductions rather occur only under unfavourable conditions. Böcker *et al.* (2018) discovered that a glyphosate ban reduces yields by about 0.5-1% which results from a reduced plant protection intensity. However, consistent field trials are mostly lacking (c.f. Wozniak and Kwiatkowski, 2012). To analyse whether the strategic choice of farmers to use glyphosate is affected by the perceptions of yield depressions or increases, we set the underlying assumption, based on the past research, that mulch seeding without glyphosate results in yield depressions (Hypothesis 3a) and the alternative with glyphosate in yield increases (Hypothesis 3b).

Hypothesis 3

a) The farmers' perception of potential yield losses decreases their preference for mulch seeding without glyphosate.
b) The farmers' perception of potential yield increases raises their preference for mulch seeding with glyphosate.

3 Data and Choice Experiment Design

In the following, we describe the data collection and the structure of the questionnaire. Then, the descriptive statistics of the sample are presented. Subsequently, we illustrate the design of the DCE.

3.1Data

For the empirical analysis, primary data was collected from German arable farmers. An online survey was developed and available for participants from October to November 2016. Farmers were invited to participate in the survey through a mailing list of the university, a reference to the study in an agricultural magazine, and social media channels. The surveys of 328 farmers were included in the evaluation, while 84 surveys could not be used since they lacked important data for the econometric analysis.

The questionnaire was structured as follows: Firstly, participating farmers were asked to provide general operating data regarding their farms. Secondly, the DCE was conducted. Next, questions were posed to identify the farmers' perceptions of different aspects of glyphosate use. Finally, socio-demographic data was collected. The farmers needed 15 minutes on average to complete the questionnaire. Table 1 summarizes the characteristics of the sample.

Table 1
Survey descriptive statistics (N = 328).

Variable	Sample Mean	(SD)	Germany[1)]
Farm acreage (total in hectares)	425.16	(718.17)	58
Hectares sprayed with glyphosate in 2016 (in % of total hectares)	23.75	(20.85)	
Occurrence of herbicide resistance[2)]	0.24	(1.31)	
Problems with black grass (in %)	32.32		
Problems with brome grass (in %)	10.67		
Problems with couch grass (in %)	32.32		
Age of respondent	43.80	(11.32)	53
Farmer is female (in %)	1.87		8
Risk assessment[3)]	5.49	(1.62)	
Region: Northwest (in %)	33.02		37
Region: East (in %)	37.38		9
Region: South (in %)	29.60		54
Respondent is the manager of the farm	65.11		28
Respondent is the farm successor (in %)	12.15		31
Farmer with university degree (in %)	36.45		10
Full-time farmer (in %)	83.00		48

1) Sources Statistical Federal Office (2010), AgriDirect Deutschland GmbH (2013), BLE (2017), Statistical Federal Office (2017)
2) Statement measured on a five-point Likert-scale from -2 = “I totally disagree” to 2 = “I totally agree.”
3) Self-assessed risk attitude on a scale from 0 = “not at all willing to take risk” to 10 = “very willing to take risk.”

It is especially remarkable that the farm size in our sample roughly matches the German average. However, the median in our sample was 109.50 hectares, which indicates that there is also a high share of smaller farms in our sample. Nevertheless, our results have to be evaluated with a focus on large farms. The average respondent was 44 years old. In the German farmer population, the average farmer was 53 in 2013 (AgriDirect Deutschland GmbH, 2013) and therefore slightly older than farmers in our sample. More than one third of the respondents had a university degree. Therefore, the share of farmers with an academic education in our sample is higher than the German farmer population, in which only 10 % have a university degree (Hemmerling et al., 2013). This might be inter alia explained by the fact that we generated our sample using an online survey. Online experiments have great advantages, since they are both low cost and able to reach many potential participants easily (Granello and Wheaton, 2004). However, access to the internet and willingness to participate in an online experiment is, to a great extent, education-dependent (Granello and Wheaton, 2004). Also, the share of farm managers in our sample is higher than the share in the German farmer population. The advantage of this is that we have a high share of decision-makers in our sample.

3.2 The discrete choice experiment

DCEs are underlying the stated preference approach, which allows for conclusions to be drawn from previously unarticulated preferences about real choice decisions (Louviere *et al.*, 2000). The attribute-based measure of respondents' preferences is thereby possible through a series of hypothetical decision-making situations (List *et al.*, 2006). In a DCE, participants are confronted with a number of choice sets, each consisting of different alternatives, and are asked to select one of the given alternatives. Each presented alternative is characterized by pre-defined attributes and their associated levels. By systematically varying the attributes and their levels, the respective influence on the selection decision can be determined (Louviere *et al.*, 2000).

The DCE utilized in this investigation presented the following decision situation to the participating farmers: the farmers had to choose between mulch seeding with or without glyphosate or could decide not to use either of these alternatives (opt-out). The opt-out alternative was included so that the choice for one of the proposed alternatives is voluntary. A forced choice could lead to inaccuracy and inconsistency with demand theory (Hanley *et al.*, 2001). Each decision situation (choice set) provided two different alternatives and the opt-out. In each decision situation, the participating farmers chose one of the alternatives that were described by the following three attributes: costs of the strategy, relationship between mechanical weed control and the use of selective herbicides, and an expected yield impact. These attributes and their levels were chosen based on the premises of relevance and complexity of the experiment. Both were addressed by reviewing the literature, seeking expert advice and conducting a pilot study with 23 arable farmers.

In the pilot study, farmers were confronted with the same attributes as in the final survey. By testing the suitability of the attributes in a pilot study, we followed the suggestion of Lancsar and Louviere (2008), who recommend this procedure as promising strategy to reduce task complexity. Task complexity increases as the number of attributes, levels or choice sets increases. This influences, on the one hand, the practicability of the experiment, since high complexity will result in increasing effort for participants. On the other hand, complexity can result in increasing unobserved variability (DeShazo and Fermo, 2002; Louviere *et al.*, 2008).

Therefore, it is recommendable in choice design to use only as many attributes and levels as is necessary. The alternatives, attributes and levels used in the experiment are presented in Table 2.

Table 2
Alternatives, attributes and levels of the DCE.

Attributes	Mulch seeding **without** glyphosate	Mulch seeding **with** glyphosate	Opt-out
Costs (in Euro per hectare)	200; 230; 260; 290		
Share of mechanical weed control in relation to the use of selective herbicides	25/75; 50/50; 75/25		None of these alternatives.
Expected yield impact (in %)	-1; -0.5; 0	0; +0.5; +1	

The design of the DCE was comprised of two alternatives and three attributes with three levels each, thus resulting in a full-factorial design of [$(3\cdot3\cdot3)_{\text{Mulch seeding without glyphosate}}$ $(3\cdot3\cdot3)_{\text{Mulch seeding with glyphosate}}$ =] 729 possible decision situations or choice sets. In this design, all possible main and interaction effects are included (Rose and Bliemer, 2009). However, for the sake of practicability, this design was determined to be too extensive and therefore, the number of choice sets was reduced. To minimize the simultaneous and unavoidable loss of information when reducing the full factorial design, a so-called "efficient design" was applied. Efficient designs (Bliemer *et al.*, 2009) require ex-ante information regarding the population's utility parameters since these designs aim to minimize the standard errors of the utility parameters for the estimation process. This information for the final experiment was obtained through a pretest with 23 farmers. As a result, a D-efficient Bayesian design (Scarpa and Rose, 2008; Bliemer *et al.*, 2009) was found to be appropriate for our purposes (D-error: 0.064). Thus, the number of choice sets presented to the participating farmers in the final survey was reduced to nine. As an example, one of the nine choice sets is depicted in Table 3.

In addition to the DCE attributes we confronted farmers with two different scenarios. In one scenario, a picture showed a high weed occurrence and in the other scenario, the picture showed less. Both pictures are shown in Appendix A.

Table 3
Example of a choice set.[1)]

Attributes	Mulch seeding **without** glyphosate	Mulch seeding **with** glyphosate	Opt-out
Costs (in Euro per hectare) ?	260	290	
Share of mechanical weed control in relation to the use of selective herbicides ?	25/75	75/25	Unchanged management
Expected yield impact (in %) ?	0	+1	
I choose:	O	O	O

1) Question marks represent "mouse over" buttons containing information about the attributes.

To ensure that farmers understood the offered attributes and levels in the DCE, we included an introductory text at the beginning of the experiment in which all attributes and their characteristics were presented. The description of the attributes remained available to participants throughout the whole experiment by placing "mouse over buttons" in each choice set. By moving the cursor over the buttons, information became visible. In this way, we ensured that the chosen attributes and levels were understood throughout the whole experiment. The introductory text for the DCE is available in Appendix B.

4 Econometric Analysis

As in Random Utility Theory (Luce, 1959; McFadden, 1974), which is the underlying framework for DCE, the estimation of farmers' valuation of the attributes is based on the assumption that the farmers' choices are dependent on the specific requirements of the experiment. Under the assumption of utility maximization, a farmer chooses the alternative for which he or she has the highest utility. Therefore, a farmer will only choose the alternative with glyphosate if the perceived utility is higher than the utility of the alternative without glyphosate or the opt-out.

In discrete choice models, the utility of alternative *j* perceived by respondent *n* in the choice situation *t* is denoted by

$$U_{ntj} = \beta_n^{'} x_{ntj} + \varepsilon_{ntj} \tag{1}$$

where x_{ntj} is described as a vector of the observed attributes, β_n is a vector of individual-specific parameters varying randomly across individuals, and ε_{ntj} represents the unobserved component of utility which is assumed to be independent and identically distributed (*iid*) extreme value.

According to Fiebig *et al.* (2010), the simple choice model in equation (1) can be extended to the GMNL specification described as:

$$U_{ntj} = \sigma_n \beta_n' x_{ntj} + \varepsilon_{ntj} \quad (2)$$

where σ_n represents the individual-specific scale parameter that allows consideration of the heterogeneity in the idiosyncratic error term. As β and σ cannot be separately identified, Fiebig *et al.* (2010) suggest formulation of the scale parameter as: $\sigma_n = \exp(\sigma' + \theta' z_n + \tau \varepsilon_{0n})$, where $\varepsilon_{0n} \backsim$ N(0,1) and z_n is a vector containing individual characteristics, with $\sigma' = -\tau^2/2$ so that $E(\sigma_n) = 1$ when $\theta = 0$.

Furthermore, the probability of respondent *n* choosing alternative *j* in the choice situation *t* is given in the GMNL as

$$\Pr(choice_{nt} = j|\beta_n) = \frac{\exp(\beta_n' x_{ntj})}{\sum_{k=1}^{J} \exp(\beta_n x_{ntj})} \quad (3)$$

with *n*=1,…,*N*; *t*=1,…,*T*; *j*=1,…,*J*. Finally, β_n is defined as:

$$\beta_n = \sigma_n \beta + \{\gamma + \sigma_n(1 - \gamma\}\eta_n \quad (4)$$

With equation (4), the GMNL-Model is differentiated from other models that regard only preference heterogeneity. It depends on a constant vector β, the scalar parameter γ, a random vector η_n and the individual-specific scale parameter σ_n.

5 Results and Discussion

5.1 Mulch seeding with or without glyphosate

To test the hypotheses, we estimated a GMNL model with correlations between the DCE attributes. The results are presented in Table 4. Model 1 thereby gives information about the mean coefficients of the attributes included in the DCE. As the standard deviations for both mulch-seeding alternatives in Model 1 are large and significant, we identified that preferences are heterogeneous across participants. In order to identify sources of heterogeneity, we analysed potentially influencing factors by including interaction terms in the model estimation, which are presented in Model 2.

The statistically significant positive coefficients of the variables *mulch seeding without* and *mulch seeding with glyphosate* indicate that farmers have a preference to choose one of the mulch seeding alternatives rather than the opt-out. Altogether, the results reveal that farmers tend to use the alternative *mulch seeding with glyphosate* (Mean = 32.17) instead of *mulch seeding without glyphosate* (Mean = 31.80). However, a Wald test shows that there is no statistically significant difference between both estimated coefficients. Therefore, we cannot support hypothesis 1a. This result is against our expectations and the findings of previous studies that highlight the importance of glyphosate use after the harvest of rapeseed (Demont *et al.*, 2008; Pekrun *et al.*, 1998; Wiese *et al.*, 2017). However, the statistically significant value of 0.18 of the interaction between the choice to use glyphosate in the DCE and the percentage of hectares treated with glyphosate on individual farms in 2016 (Model 2) shows that the general willingness to use glyphosate increases with the share of acreage treated in 2016. This might indicate that a share of farmers in the sample have, in general, a preference for the use of glyphosate.

5.1.1 Influence of weed occurrence

To test whether the occurrence of weeds and volunteers after the harvest of rapeseed and before sowing wheat influences the farmers' choice for or against glyphosate, we confronted farmers with two different scenarios. In one scenario, a picture showed a high weed occurrence and in the other scenario, the picture showed less (pictures are available in Appendix A). As displayed by Model 2, a high weed occurrence decreases the farmers' preference to use mulch seeding without glyphosate instead of the opt-out (Mean = -1.95). However, there is no significant difference between the decision to use mulch seeding with glyphosate or the opt-out. Therefore, it is remarkable that for controlling weeds in pre-sowing, farmers either prefer mulch seeding with glyphosate or other strategies that are implemented in their opt-out decision. This might be, e.g., ploughing or using a mulcher.

Furthermore, we asked farmers to mention potential problem weeds on their farms. This enabled investigation of the interactions between mulch seeding with glyphosate and the weeds black grass, brome grass and couch grass in the model estimation. We found that the occurrence of black grass (Mean = 1.74) and couch grass (Mean = 1.14) increase the farmers' preference to use mulch seeding with glyphosate.

Altogether, we cannot fully support Hypothesis 1b as we can only detect a negative influence of high weed pressure on the farmer preference to use mulch seeding without glyphosate.

However, in addition to other status quo strategies, the use of mulch seeding with glyphosate is preferred over mulch seeding without glyphosate if weed pressure after harvest is high.

Table 4
Results of the GMNL-Model without and with interactions.

Variable	Mean (SD)			
	Model 1		Model 2	
Alternatives and attributes:				
Mulch seeding without glyphosate	31.80***	(23.09***)	32.97***	(26.49***)
Mulch seeding with glyphosate	32.17***	(21.48***)	28.39***	(24.11***)
Share of selective herbicides (per 10 percent)	-1.64**	(0.04***)	-1.07	(2.55**)
Yield decrease	-2.11***	(3.83***)	-2.24**	(3.24***)
Yield increase	1.84***	(1.60**)	2.15**	(2.13**)
Cost	-0.07***	(0.06***)	-0.08***	(0.08***)
Interactions without glyphosate use.				
High weed occurrence[1)] × without glyphosate			-1.95**	
Farm size (per 100 ha) × without glyphosate			0.33**	
Interactions with glyphosate use.				
Herbicide resistance[2)] × with glyphosate			0.38	
Risk attitude[3)] × with glyphosate			0.27	
Farm size (per 100 ha) × with glyphosate			0.46***	
High weed occurrence[1)] × with glyphosate			-0.04	
Glyphosate use 2016[4)] × with glyphosate			0.18***	
Black grass[5)] × with glyphosate			1.74**	
Brome grass[5)] × with glyphosate			1.02	
Couch grass[5)] × with glyphosate			1.14*	
Interactions with share of selective herbicides				
Herbicide resistance[2)] × share of selective herbicides			-1.32*	
Risk attitude[3)] × share of selective herbicides			-0.17	
Farm size (per 100 ha) × share of selective herbicides			-0.04	
Black grass[5)] × share of selective herbicides			-2.15*	
Brome grass[5)] × share of selective herbicides			0.49	
Couch grass[5)] × share of selective herbicides			0.49	
Scale heterogeneity tau	1.09***		1.11***	
Goodness of fit				
Log-Likelihood	-1,646.64		-1,571.50	
AIC	3,349.28		3,230.99	

Notes: ***$p < 0.001$; **$p < 0.01$.; *$p < 0.05$; participants = 328; observations = 8,856; software STATA 15; number of random Halton draws = 1,000. Random parameters are allowed to correlate.

1) Two scenarios were tested. First, less weed occurrence after oilseed rape. Second, high weed occurrence after oilseed rape. Scenarios were presented as pictures available in Appendix A. Effect coded variable: -1 = no weed occurrence; 1 = high weed occurrence.
2) Statement "Herbicide resistance towards selective herbicides are an issue on my farm" measured on a five-point Likert-scale from -2 = "I totally disagree" to 2 = "I totally agree."
3) Self-assessed risk attitude on a scale from 0 = "not at all willing to take risk" to 10 = "very willing to take risk."
4) Percentage of hectares on own farm treated with glyphosate in 2016.
5) Effect coded; reference: black grass (brome grass, couch grass) is not a problem weed

5.1.2 Influence of farmers' risk attitude

The participating farmers tended to be risk neutral or slightly risk seeking (Mean = 5.49; Median = 6.00); however, their risk attitude had no statistically significant ($p > 0.1$) influence on the use of glyphosate. This result is contrary to our expectations. The non-significance of the risk attitude may be caused by the ambiguity of whether the use of pesticides is a risk-increasing or risk-reducing action. While farmers may use glyphosate as a risk-reducing tool for controlling weeds, glyphosate simultaneously has the potential to increase risk by raising income variability (Pannell, 1991) and causing negative externalities (Wilson and Tisdell, 2001; Brethour, 2002). Therefore, we cannot support Hypothesis 1c for farmers in Germany.

5.1.3 Influence of farm acreage

With increasing farm acreage, farmers are more likely to choose one of the mulch seeding alternatives instead of the opt-out. Furthermore, the coefficient for the interaction *farm size* × *mulch seeding with glyphosate* (Mean = 0.46) is higher than the coefficient for *farm size* × *mulch seeding without glyphosate* (Mean = 0.33), meaning mulch seeding in general and the glyphosate strategy in particular is mostly preferred by large farms. These results support Hypothesis 1d and are in line with the findings of Wiese *et al.* (2017). With increasing farm size, the demand for skilled labor and dependence upon herbicides for timely weed control increase (Young, 2006). Therefore, farmers with large farms may use glyphosate because it is more time efficient than weed control with selective herbicides or an additional mechanical weed control.

5.2 Mechanical weed control vs. selective herbicides

In Model 1, the coefficient for the attribute *share of selective herbicide use* is statistically significant and has a negative sign (Mean = -1.64). That means farmers in general prefer mechanical weed control in pre-sowing versus the use of post-emergence selective herbicides in the crop rotation of winter wheat after rapeseed. Therefore, Hypothesis 2a can be confirmed. Although mechanical weed control is more costly and labour-intensive (Llewellyn *et al.*, 2012; Böcker *et al.*, 2018), farmers seem to count on the advantages of mechanical weed control, which could have a positive influence on the soil condition in addition to effectively controlling weed populations (Givens *et al.*, 2009; Peigné *et al.*, 2007). Furthermore, problems with herbicide resistance might play a role in the farmers' preference for mechanical weed control, which is analysed in the following.

5.2.1 Herbicide resistance towards selective herbicides

In line with our expectations, existing resistance towards selective herbicides increases the farmers' preference to use mechanical weed control instead of selective herbicides (Hypothesis 2b). This is indicated by the negative coefficient for the interaction *herbicide resistance* × *share of selective herbicides* with a mean of -1.32. Because only 15-20 modes of action are available in present herbicides (Cobb and Kirkwood, 2000), farmers are limited in their choice of selective herbicides for weed control. Additionally, the admission of new herbicides to the market with innovative modes of action has decelerated considerably (Rüegg *et al.*, 2007).

5.2.2 Glyphosate use against herbicide resistance towards selective herbicides

Contrary to our expectations, the presence of herbicide resistance towards selective herbicides has no influence on the farmers' preferences for glyphosate use (Mean = 0.38). Therefore, we cannot support Hypothesis 2c. However, the significant negative interaction *black grass* × *share of selective acting herbicides* with a mean of -2.15 shows that the use of selective herbicides is unfavourable with a high occurrence of black grass. For this particular weed, herbicide resistance is a critical issue (Heap, 1997; Heap, 2014). Moreover, in this case, farmers prefer to use glyphosate to tackle black grass occurrence (Mean = 1.74). Therefore, rather than a general tool to overcome weed resistance towards selective herbicides, glyphosate is being used as specific tool to control particular weeds like black grass.

5.3 Yield impact

As expected, potential yield effects influence the farmers' choice between a mulch seeding strategy with or without glyphosate. In particular, the farmers' perception of potential yield losses decreases their preference for the alternative of mulch seeding with glyphosate (Mean = -2.11), while potential yield increases have the opposite effect (Mean = 1.84). It should be noted that the effect of yield losses is higher than the effect of yield increases. This is in line with the literature about loss aversion, which states that the pain of losing is greater than the satisfaction of an equivalent gain (Kahneman and Tversky, 1982).

Cook *et al.* (2010), Garvert *et al.* (2013) and Böcker *et al.* (2018) expect appreciable yield depression without glyphosate, which is in line with the analysed perceptions of farmers. Altogether, we confirm Hypothesis 3a and b. However, consistent field trials are needed for a definitive evaluation of potential yield effects of glyphosate.

6 Conclusions

This paper contributes to the literature on farmers' preference for glyphosate application. In addition, this research adds to the literature analysing preferences through the utilization of a DCE that allows estimation of the trade-offs between different agronomic strategies as well as between their components. The central result of this investigation is that farmers have no clear preference for glyphosate use in combination with mulch seeding after the harvest of rapeseed. However, high weed pressure, the occurrence of specific problem weeds and larger farm size all increase the farmers' preference for glyphosate use. After rapeseed harvest, farmers prefer mechanical weed control over the use of selective herbicides in pre- or post-emergence. Furthermore, the occurrence of weed resistance towards selective herbicides increases the farmers' preference for mechanical weed control.

In addition, potential yield effects influence the farmers' decision for a mulch seeding strategy with or without glyphosate. As yield losses have a higher impact on the farmers' decision than yield gains, our results reveal the presence of loss aversion, meaning that the pain of losing is greater than the satisfaction of an equivalent gain. Altogether, we conclude that farmers prefer the use of glyphosate as it is an important part of their agronomic strategy to prevent weed infestation and to save work and labour costs, especially on larger farms.

The results of this study are an important contribution to the discussion about the use glyphosate as well as its potential prohibition. In this context, four major policy and research implications are derived from the results of this study.

The first policy implication relates to the decision about the authorization of glyphosate in the future. It is suggested that policymakers consider the utility of glyphosate as part of an agronomic strategy that allows farmers to control weeds and volunteers as efficient as possible. Our results reveal the importance of glyphosate for controlling specific weeds like black grass where selective herbicides are unhelpful because of herbicide resistances. Furthermore, potential yield effects of glyphosate have to be considered in the decision about the future authorization of glyphosate. Therefore, conducting consistent field trials is suggested for future research.

The second implication relates to the use of selective herbicides. If weed pressure is high farmers rely on herbicides for controlling weeds in an effective and economic feasible way. As weed resistances towards selective herbicides are an issue for farmers, policy is advised to support the research and admission for innovative modes of actions in herbicides.

The third implication relates to the externalities of herbicide use. Potential negative impacts for human health, ecosystems and agricultural system stability have to be clarified and avoided. It is suggested to develop strategies that allow an effective but unhesitating use of herbicides. This comprises an effective transfer of knowledge and a sensitization for an appropriate herbicide use. Focusing on integrated crop protection approaches might be an important approach in this context. This is especially relevant as our results reveal that a general use of glyphosate is favourable for some farmers in our sample.

Finally, the fourth implication relates to the analyses of glyphosate in further crop rotations. This study focussed on the crop rotation winter wheat after rapeseed. As the attributes and levels in the experiment are dependent of the crop rotation it was not possible to confront farmers with more than one crop rotation because of task complexity. Therefore, it is suggested for future research to analyse the glyphosate use in further crop rotations.

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Appendix A. Scenarios of weed occurrence

Scenario 1: Low weed occurrence. Only volunteer oilseed rape.

Scenario 2: High weed occurrence after oilseed rape.

Appendix B. Introductory Text of the Discrete Choice Experiment

"Please imagine that you have to decide about the treatment of your field during the cultivation of winter wheat after the harvest of oilseed rape. In the following, you will be asked nine times whether you would like to use glyphosate or not. Please consider each decision situation independently of the others. We are interested in your personal opinion. Therefore, there are no "wrong" answers. Within the experiment, you will always be given the possibility to choose an "opt out" alternative which allows choosing none of the mulch seeding alternatives. The offered mulch seeding alternatives vary - besides the use of glyphosate - in the following three attributes: the share of mechanical weed control in relation to the use of selective herbicides, potential yield effects of the use or the non-use of glyphosate, and the costs of a mulch seeding alternative."

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Die Wurzeln der **Fakultät für Agrarwissenschaften** reichen in das 19. Jahrhundert zurück. Mit Ausgang des Wintersemesters 1951/52 wurde sie als siebente Fakultät an der Georgia-Augusta-Universität durch Ausgliederung bereits existierender landwirtschaftlicher Disziplinen aus der Mathematisch-Naturwissenschaftlichen Fakultät etabliert.

1969/70 wurde durch Zusammenschluss mehrerer bis dahin selbständiger Institute das **Institut für Agrarökonomie** gegründet. Im Jahr 2006 wurden das Institut für Agrarökonomie und das Institut für Rurale Entwicklung zum heutigen **Department für Agrarökonomie und Rurale Entwicklung** zusammengeführt.

Das Department für Agrarökonomie und Rurale Entwicklung besteht aus insgesamt neun Lehrstühlen zu den folgenden Themenschwerpunkten:

- Agrarpolitik
- Betriebswirtschaftslehre des Agribusiness
- Internationale Agrarökonomie
- Landwirtschaftliche Betriebslehre
- Landwirtschaftliche Marktlehre
- Marketing für Lebensmittel und Agrarprodukte
- Soziologie Ländlicher Räume
- Umwelt- und Ressourcenökonomik
- Welternährung und rurale Entwicklung

In der Lehre ist das Department für Agrarökonomie und Rurale Entwicklung führend für die Studienrichtung Wirtschafts- und Sozialwissenschaften des Landbaus sowie maßgeblich eingebunden in die Studienrichtungen Agribusiness und Ressourcenmanagement. Das Forschungsspektrum des Departments ist breit gefächert. Schwerpunkte liegen sowohl in der Grundlagenforschung als auch in angewandten Forschungsbereichen. Das Department bildet heute eine schlagkräftige Einheit mit international beachteten Forschungsleistungen.

Georg-August-Universität Göttingen
Department für Agrarökonomie und Rurale Entwicklung
Platz der Göttinger Sieben 5
37073 Göttingen
Tel. 0551-39-4819
Fax. 0551-39-12398
Mail: biblio1@gwdg.de
Homepage : http://www.uni-goettingen.de/de/18500.html